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Nitrate Removal from Contaminated Water Supplies. Volume 1. Design and Initial Performance of a Nitrate Removal Plant

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NITRATE REMOVAL FROM CONTAMINATED WATER SUPPLIES
VOLUME I. DESIGN AND INITIAL PERFORMANCE OF A NITRATE REMOVAL PLANT

by

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Cooperative Agreement No. CR808902-02-0

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16. ABSTRACT

This report reviews the design, construction, and operation of a 1-mgd nitrate removal plant in McFarland, CA. The plant treats well water for domestic use. Nitrates are reduced from approximately 15.8 mg NO_3-N/L to well below the maximum contaminant level of 10 mg NO_3-N/L.

Continuous daily (24-hr.) operation of the plant was made possible by automatic operation. Automatic nitrate monitoring of product water was performed once an hour through the use of modified ion chromatography. Daily records of flows, water quality, electrical consumption, salt usage, and manhours were kept to determine operating costs.

The total wastewater produced by the nitrate plant was 3.39% of the amount of water delivered to the distribution system from the well. The treated water was 75% of water delivered. Saturated brine was 0.09%, dilute brine was 0.49%, rinse water was 1.76%, and backwash water was 1.14%. All percentages were of the blended water delivered to the distribution system. All waste from the plant was discharged to the McFarland municipal wastewater treatment system, with ultimate discharge to 120 acres of cotton and alfalfa crops.

The amount of water treated by each ion exchange vessel before regeneration was 165,900 gal. (260 bed volumes). The amount of salt used per regeneration was 6.35 lb/ft^3 of resin.

Capital costs totaled $355,638 for a 5-ft. bed system. Operation and maintenance costs were $0.13 per thousand gal. when the system was operating at 1 mgd. Total costs, including operations and maintenance (O&M) and amortized capital, were $0.25 per 1000 gal. when operating at design capacity of 1 mgd.

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxics Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our Nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal and industrial wastewater discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controllability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the research and the user community.

The pollution of our Nations' groundwater has been called the environmental problem of the 1980s. When polluted groundwater serves as a source of public drinking water, pollutants must be removed to levels below standards regulated by the Safe Drinking Water Act (Public Law 93-523). Nitrate is one of the pollutants frequently found in groundwater used for drinking water supplies and is the cause of serious and occasionally fatal poisonings in infants. This report summarizes studies being conducted in behalf of small communities on processes for removal of nitrate from groundwater supplies.

ABSTRACT

This report reviews the design, construction, and operation of a 1-mgd nitrate removal plant in McFarland, California. The plant treats groundwater pumped from one of the wells supplying water for domestic use. Nitrates are reduced from approximately 15.8 mg/L NO_3-N to well below the maximum contaminant level of 10 mg/L NO_3-N. Included in the design considerations are such factors as water supply, health and safety, level of technology, location, capacity, regeneration frequency, water quality, operational sequence, brine disposal, automatic operation, and performance monitoring. The procedures for both manual and automatic operation are discussed.

Continuous daily (24-hr.) operation of the plant was made possible by automatic operation. The presence of the operator is required for approximately 1 hr. per day to check performance. Automatic nitrate monitoring of product water was performed once an hour through the use of modified ion chromatography. Daily records of flows, water quality, electrical consumption, salt usage, and manhours were kept to determine operating costs.

The total wastewater produced by the nitrate plant was 3.39% of the amount of water delivered to the distribution system from the well. The treated water was 75% of water delivered. Saturated brine was 0.09%, dilute brine was 0.49%, rinse water was 1.76% and backwash water was 1.14%. All percentages were of the blended water delivered to the distribution system. All waste from the plant was discharged to the McFarland municipal wastewater treatment system, with ultimate discharge to 120 acres of cotton and alfalfa crops.

The amount of water treated by each ion exchange vessel before regeneration was 165,900 gal. (260 bed volumes). The amount of salt used per regeneration was 6.35 lb/ft3 of resin.

Capital costs totaled $311,118 for a 3-ft. bed system, and $355,638 for a 5-ft. bed system. Operation and maintenance costs were $0.13 per thousand gal. when the system was operating at 1 mgd. Total costs, including operations and maintenance (O&M) and amortized capital, were $0.25 per 1000 gal. when operating at design capacity of 1 mgd.

This report was submitted in fulfillment of Cooperative Agreement No. CR808902-02-0 by McFarland Mutual Water Company under the sponsorship of the U.S. Environmental Protection Agency. Boyle Engineering Corporation served as subcontractor. This report covers the period June 1, 1984 to November 30, 1984, and work was completed as of October 30, 1986.

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SECTION 1

INTRODUCTION

This report reviews the operation of a 1-mgd nitrate removal plant at McFarland, California. The plant and supporting equipment are described, and an analysis of the capital cost of construction and the operation and maintenance (O & M) costs are also presented. The data on which this report is based were obtained during the initial adjustment period of the plant and during the first 6 months of automatic operation ending November 30, 1984.

The plant uses the ion exchange process with commercially available resin. The process design is based on the research and pilot studies performed under a previous U.S. Environmental Protection Agency (EPA) cooperative agreement. Reference 1. The design and operation of the plant were supported by McFarland Mutual Water Co. (McFMWCo) and EPA under cooperative agreement Nos. CR80802-010 and CR80802-020. Construction of the plant was made possible with funds from MCMWCo, The Kern Co. Community Development Agency (CDA), and the Kern County Water Agency (KCWA). The CDA is funded by the U.S. Department of Housing and Urban Development (HUD).

This report is the first of a two volume final report under the existing grant and is restricted to the general subject of the initial operation of the plant. The second volume will include a report on the continuing operation of the plant for several additional months.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

1. The plant was automatically operated for a 6 month period and gave the following performance characteristics averaged over the operating period:

   a. Nitrate leakages averaged 5.2 mg NO3-N/L or 23.2 mg in a blend of treated and untreated water.

   b. The blend consisted of 76.1% treated water and 23.9% untreated water.

   c. Brine dosages were 6.36 lb of salt per ft3 foot of resin, or 2.49 lb per thousand gal of blended water.

   d. Brine efficiencies averaged 10.3 equivalents of chloride per equivalent of nitrate removed and varied from a low of 8.3 to a high of 11.8.

   e. Water recovery was 96.7% of the water pumped. The remaining 3.3% was discarded as waste brine and wash water.

   f. Wastewater per thousand gal of blended water consisted of 0.92 gal of saturated brine (4.9 gal of dilute brine) 17.6 gal of rinse water, and 11.4 gal of backwash water.

2. Maximum automation was used successfully to satisfy the minimal manpower requirements of a small water system operator. The plant was designed and is being demonstrated primarily with the needs of small communities in mind where wells and distribution systems are already in place. The plant operates at a well site rather than as a central treatment plant.

3. Raw water composition varied during this period of operation. Nitrate varied from 16.0 mg NO3-N/L or 71.0 mg NO3/L to 11.07 mg NO3-N/L or 49.0. Sulfate varied from 115 to 60 mg/l. This provided the opportunity to measure the effect of changing water composition on plant performance.

4. Resin beds were operated at 76% capacity during this initial adjustment period to prevent over-runs which could occur because of operational problems.

5. The effect of operating at less than 100% capacity is estimated to be a decrease in brine efficiency of approximately 18%.

6. Brine efficiency, nitrate leakage, and bed volumes to nitrate breakthrough can be accurately predicted from ion exchange theory. Computer based programs being developed can simulate effluent histories and are comparable to those obtained from the plant. They also give chromatographic distributions of ions within spent beds.

7. A 3-ft. resin bed depth was used during this period of operation. A 5-ft bed will be used in future tests to obtain comparative data.

8. The power consumed by the plant is 244 kwh per million gal of blended water. This amount is 10% of the total power required for pumping at the well site.

9. Capital costs were $311,118 for a plant with the 3-ft-deep resin bed and $355,683 for a plant with a 5-ft bed. The total costs are $0.245 per 1000 gal of blended water for the 5-ft bed plant (1983 costs). During this report period the plant was operated at only 13.7%. capacity. The overall cost to the McFarland community for nitrate removal during this period was $0.162 per 1000 gal water consumed.

10. The plant is totally automatic in operation with automatic nitrate analysis for monitoring, and automatic shut down if nitrate exceeds the MCL in the product water. Computer printouts of operating data are obtained on a daily basis and if alarms occur.

11. Operator tasks are reduced to approximatly 1 hr per day and include routine inspection, maintenance, and record-keeping.

12. Nitrate removal is economically and technically feasible by the ion exchange process. The most undesirable feature is the production and disposal of waste brine. At McFarland during this report period, approximately 1300 lbs of waste salts were disposed of in the plant wastewater daily by discharging to the municipal waste water system. If the plant were operated 24 hrs/per day, the daily salt discharge would be 2500 lb in 33,000 gal of wastewater. Close monitoring of soil and plant conditions at the disposal site is being conducted.

13. Although nitrate removal by the ion exchange process is largely being considered as a process adaptable for small communities, it is the latter who will find the waste disposal problems the most difficult to solve. Improvements in the process are still required to reduce quantities of waste salts. These can

probably be accomplished by use of highly selective nitrate resins, brine recirculation, recovery and separation of sodium nitrate and sodium chloride, and close adjustment of plant operation to changes in raw water composition.

14. Plant shut-downs were due to malfunctions of electrical and mechanical equipment and leaks in plastic pipe. All repairs were handled by water company personnel.

15. The adjustment and operation of the plant was complex because by using the same microprocessor for plant control and data collection and reporting. Considerable operating time was lost due to writing and testing the data collection portion of the program. The controller required programming by ladder logic which is cumbersome as a computer language. A separate computer is recommended for data collection at a similar installation.

16. Ion chromatography is satisfactory for routine anion analysis and research but definitely requires improvement for continuous on-stream plant monitoring. Additional research on a continuous nitrate monitor that will shut the plant down if nitrate concentration exceeds the MSCL is recommended.

17. Further development of the nitrate selective resin is recommended because use of a nitrate selective resin would eliminate the possibility of nitrate dumping.

18. Further research on waste brine disposal and brine reuse is recommended to elimiate the problem of waste nitrate and waste salt contamination of the disposal area and underlying groundwater.

SECTION 3

CONSTRUCTION OF PLANT

BACKGROUND OF PROJECT

McFarland

McFarland, California is an incorporated city of approximately 5,000 persons (4,177 - 1970 census and 5,765 - 1980 census) located on U.S. Highway 99, approximately 20 miles north of the city of Bakersfield in Kern County. Like many small San Joaquin Valley communities, much of McFarland's economy is based on agriculture and agricultural-related business.

Water Supply

The McFarland Mutual Water Company supplies water from its wells and through its distribution system for municipal use. The only water source at present is underlying groundwater. Six wells are located in McFarland. Use of Well No. 3 has been discontinued for public use due to high nitrate levels. Well 2 is the location of the nitrate plant now in operation. Recent analysis of Wells 1 and 4 show nitrates above the Maximum Contaminant Level.

Water quality of four wells containing high nitrates are given in Table 1. Due to recent and projected development trends, two new wells were recently constructed to serve the developing areas in a remote part of the City and will shortly be in operation.

The static water level in the wells is approximately 250 feet below the surface. Except for excessive nitrate levels, the water is of generally good quality.

McFarland Nitrate History

Water quality data show significant nitrate levels present in water supplied by McMWCo. before 1965. In 1978 McMWCo. requested and received a Cooperative Agreement to study treatment from the U.S. EPA. As a result of this work, as reported in Reference 1, significant insight into the ion exchange process was achieved and it was realized that operating cost reductions and waste brine reduction could be anticipated through further research on nitrate selective resins. However, due to the pressing need to have an operating system McMWCo. decided to proceed with the construction of a full scale plant using readily available ion exchange technology. The design allows adequate instrumentation metering and process

TABLE 1 COMPOSITION OF McFARLAND WELL WATER (ppm) IN 1980

Item	Well No. 1	2	3	4
Date	5-8-80	4-9-80	5-1-80	4-16-80
Calcium	28	88	156	78
Sodium	50	65	100	72
Bicarbonate	88	102	121	95
Chloride	28	86	94	51
Sulfate	51	105*	310	182
Nitrate+	30	67*	98	47
TDS	235	466	827	485
ph	7.7	7.2	7.3	7.7

*Analyses on 5/31/78 showed sulfate levels of 261 ppm and nitrate levels of 78 ppm

+Concentration of nitrate listed as mg NO3/L. To convert to mg NO3-N/L divide by 4.43

flexibility to allow close monitoring and testing of future process improvements as well as provide detailed operating costs for a base line or state-of-art system. The design also allows use of improved resins and expansion for brine recirculation and recovery.

Basis of Plant Design

The major considerations given to the design of the McFarland plant can be listed as:

Health and Safety
Level of Technology
Location
Capacity
Regeneration Frequency
Water Quality
Operational Sequence
Brine Disposal
Automatic Operation
Monitoring of Performance

Health and Safety

This is the major consideration and took precedence where design conflicts arose. The plant design was reviewed by the California State Division of Health who issued an operating permit on May 13, 1983. Prior to issuance of the permit a design review was conducted. The major concern was that:

1. Brine be isolated from the brine water supply system. This is accomplished with a double check valve.

2. Waste brine and wash water be isolated from the distribution system. Accomplished by double valves or "block and bleed" arrangement.

3. Nitrate levels in supply water be kept below 10.0 mg NO3-N/L or 44.3 mg NO3/L and preferably at 6.8 mg NO3-N/L or 30.0 mg NO3/L.

4. A Class 2 State certified operator be made responsible for plant operation. Two employees of McMWCo. will qualify for this certification.

The reason for the first two requirements was the concern of health officals that waste nitrate in concentrated amounts could contaminate the water supply if valves malfunctioned and cross connections occured. This is a major concern of health officials for all water treatment systems. Ion exchange is being suggested as a treatment for removal of arsenic and radioactive contaminants. These safety precautions built into the McFarland plant can be useful to demonstrate and promote safe operation of ion exchange treatment of other contaminants.

Level of Technology

The technology used in the mechanical design and planning for the plant relies heavily on that used in the water softening industry. The chemical process design is based on research in use of anion exchange resins completed under previous EPA grants. (Reference 1) Although that research indicated efficiency may be improved by further research on nitrate selective resins it was determined by the principal investigator and the EPA Project Officer to use conventional commercially available strong base anion exchange resin as a basis for design. The plant would thus provide base line data against which improved resins and other process improvements could be measured. The process did incorporate the partial regeneration mode of operation which had been demonstrated under the research program mentioned above and which is not used in the water softening industry.

Location

Plant location at one of the well sites was dictated by the already-in-place well and distribution system which had been in use for several years (over 30) and is typical for small communities dependent on groundwater. Such systems develop over a period of time usually by placing wells closest to the distribution system serving a developing area without regard for centralized treatment. McFarland can draw water from any of the six wells which can pump water to an interconnected distribution system and thus supply water to any part. Due to the lack of a centralized distribution system the plant had to be designed to operate from a single well. Well pumps operate on a demand basis, consequently, the plant had to be able to operate in an automatic on-off basis. This obviated the need for on-site storage of water which would have added considerably to the cost. The design was made to accept water directly from the well pump, treat for nitrate removal, and allow treated water to flow directly into the distribution system without directing the treated water to a central part of the system and without storage.

Capacity

The delivery capacity of Well No. 2 is approximately 695 gallons per minute (gpm) (1 mgd on a continuous basis). With nitrate levels in the 15.8 mg NO3-N/L or 70.0 mg NO3/L range. A 6.8 mg NO3-N/L or 30.0 mg NO3/L product can be achieved by reducing nitrate to 0 in 70 percent of the water and blending with untreated water. Studies (Reference 1) show a decrease regeneration efficiency as nitrate leakage in treated water approaches zero. See Figure 1. Since chemical costs are significant, savings can be realized by use of a larger plant capacity and partial regeneration of the bed. Furthermore, no reliance can be placed on nitrate levels remaining in the 15.8 mg NO3-N/L or 70.0 mg NO3/L range in the future. If these values did rise, treatment of all water produced would definitely be required.

The plant was sized to treat the total well production rate and provide a blending facility to allow a range of treatment levels from partial to complete and provide sufficient capacity to meet rising nitrate levels.

Regeneration Frequency

Anion exchange resins require regeneration with a sodium chloride brine. It is necessary to have a standby regenerated bed of resin in a second vessel starting into operation when the first starts its regeneration cycle if uninterrupted service is desired.

Regeneration times (in McFarland about 120 minutes) are fixed regardless of bed size while bed exhaustion times or service periods vary with size of bed and bed capacity (See Table 2). Bed exhaustion time should be longer than the regeneration time if two beds are used. In the McFarland Plant with three beds in a staggered flow arrangement this regeneration must be completed while one-half of a bed is exhausted, i.e. the service period for one vessel must be over 240 minutes. The service period is a function of bed size, resin capacity, and feed water concentration of nitrate, sulfate, bicarbonate and chloride. In McFarland's plant variability in water quality and capability to adjust bed depth from 3 to 5 feet provides service time per vessel of 6 to 20 hours providing adequate time for regeneration.

Other considerations can also enter into determining regeneration frequency. If an insufficient standby supply is available, it may be desirable to increase bed size to allow for repair and maintenance of standby beds (repair of major equipment in McFarland requires at least three working days). Or if only manual regeneration is required it would be desirable to size beds for once per day service periods for operator convenience.

In McFarland it would be prohibitively costly to size the beds for a three day service period. If extensive repair and maintenance cannot be completed within the standby period the system can be shut down and other wells placed in operation or the plant can be operated at at least 50 percent capacity if two vessels are operable.

Long standby periods require larger beds and added resin inventory and equipment costs. Bed size is also limited in that deeper beds give higher backpressure while large area beds give lower flow rates

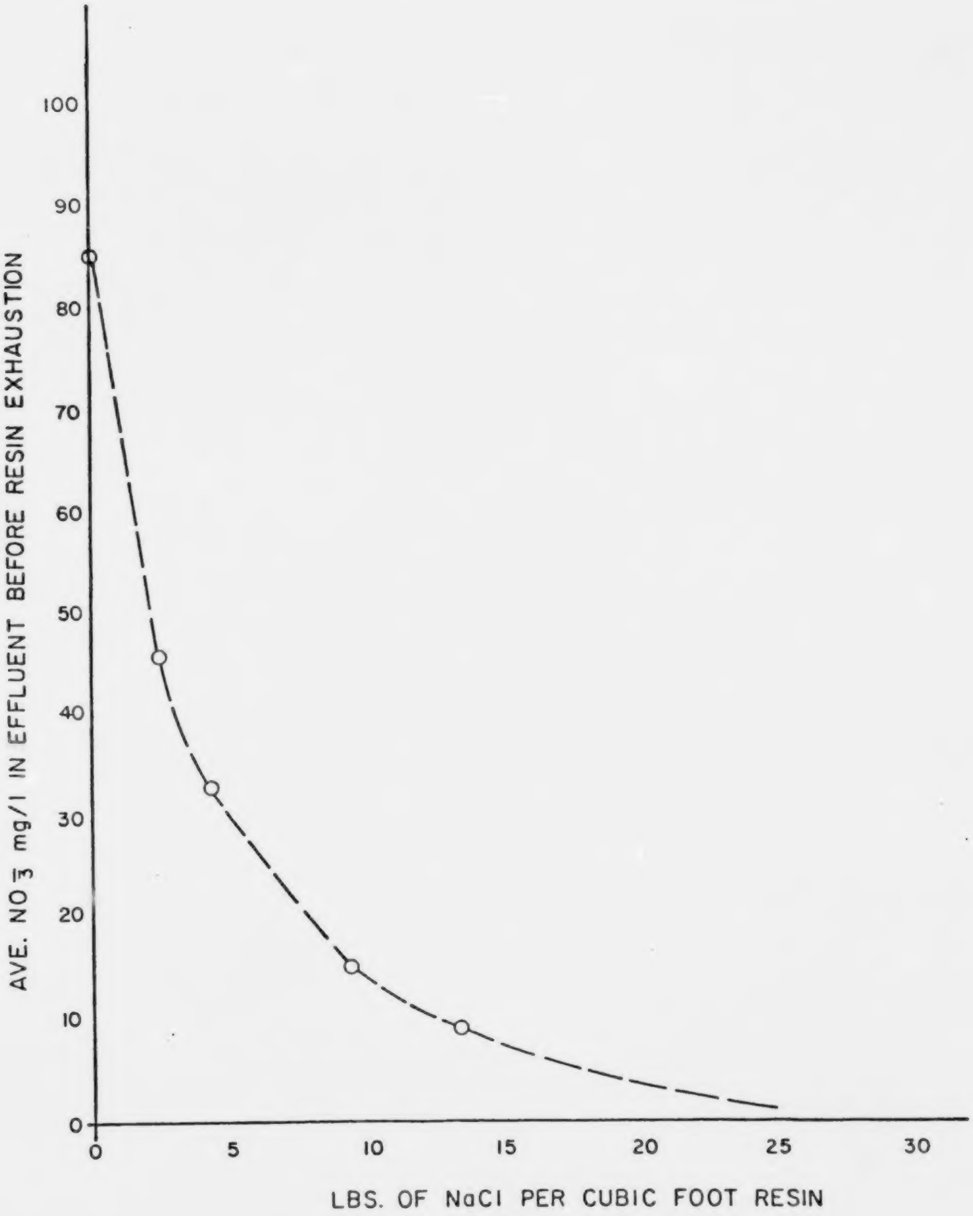

FIGURE 1 TYPICAL NITRATE LEAKAGE DEPENDENCE ON SALT DOSE

TABLE 2 ESTIMATED NO. OF REGENERATIONS PER VESSEL PER DAY

Bed Volumes Treated	Percent Treated Water in Blend and Bed Depth							
	100%		75%		50%		25%	
	3 ft	5 ft	3 ft	5 ft	3 ft	5 ft	3 ft	5 ft
200	2.67	1.60	2.00	1.20	1.34	0.84	0.67	.40
300	2.00	1.20	1.50	0.90	1.00	0.60	0.50	.30
400	133*	0.80+	1.00	0.6	0.67	0.40	0.33	.20

* Twelve hour service period per vessel and 6-hr standby per vessel.

+ Twenty hour service period per vessel and 10-hr standby per vessel.

(hydraulic loading) which promote reverse adsorption or "dumping" of nitrate from resin to product water.

Water Quality

Water quality is an extremely important factor in nitrate ion exhange technology. Two areas of concern are:

1. All major anions interfere to reduce bed capacity and change product water quality.

2. Resin-ion equilibria and flow rate effects must be taken into consideration to obtain proper bed operation.

Bed capacity, BV(N) or bed volumes treated per bed volume of resin to nitrate breakthrough, is a function of the concentration of all anions in the feed water. Sulfate ion is the greatest offender. For the composition of Well 2 water given in Table 1, BV(N) is estimated as 351 bed volumes, if sulfate rises to 200 mg/l and nitrate to 16.9 mg NO3-N/L or 75.0 mg NO3/L, BV(N) is reduced to 228. Chloride must be increased over 550 mg/L to have the same effect and bicarbonate even greater. The interferrence of sulfate is the main reason for not building a nitrate demonstration facility at Well 3.

Product water quality is changed due to removal of influent ions and replacement by chloride. All sulfate is converted to chloride throughout the run. Bicarbonate varies being low in the beginning and rising toward the end of the run. This gives a product of increasing alkalinity which is most corrosive at the start of the run. See Figure 2. In the McFarland design water of low corrosivity is blended 1-1 with water of higher corrosivity by using two vessels in a staggered flow arrangement during service.

Another water quality consideration is the amount of chloride increase in product water due to removal of sulfate and nitrate. At Well 2 the removal of 98 mg/l sulfate and 14.0 mg NO3-N/L or 62.0 mg NO3/L increases chloride by 106.5 mg/l; bringing the total to approximately 200 mg/l.

Operational Sequence

The operational sequence is selected either through a programmable controller or manual push-button operation on each vessel. Each vessel undergoes the following sequence:

1. Service. Raw water passes through the resin bed to exchange nitrate and chloride ions until bed capacity is used.

2. Brine Injection. A sodium chloride brine is passed through the bed to remove nitrate from the resin.

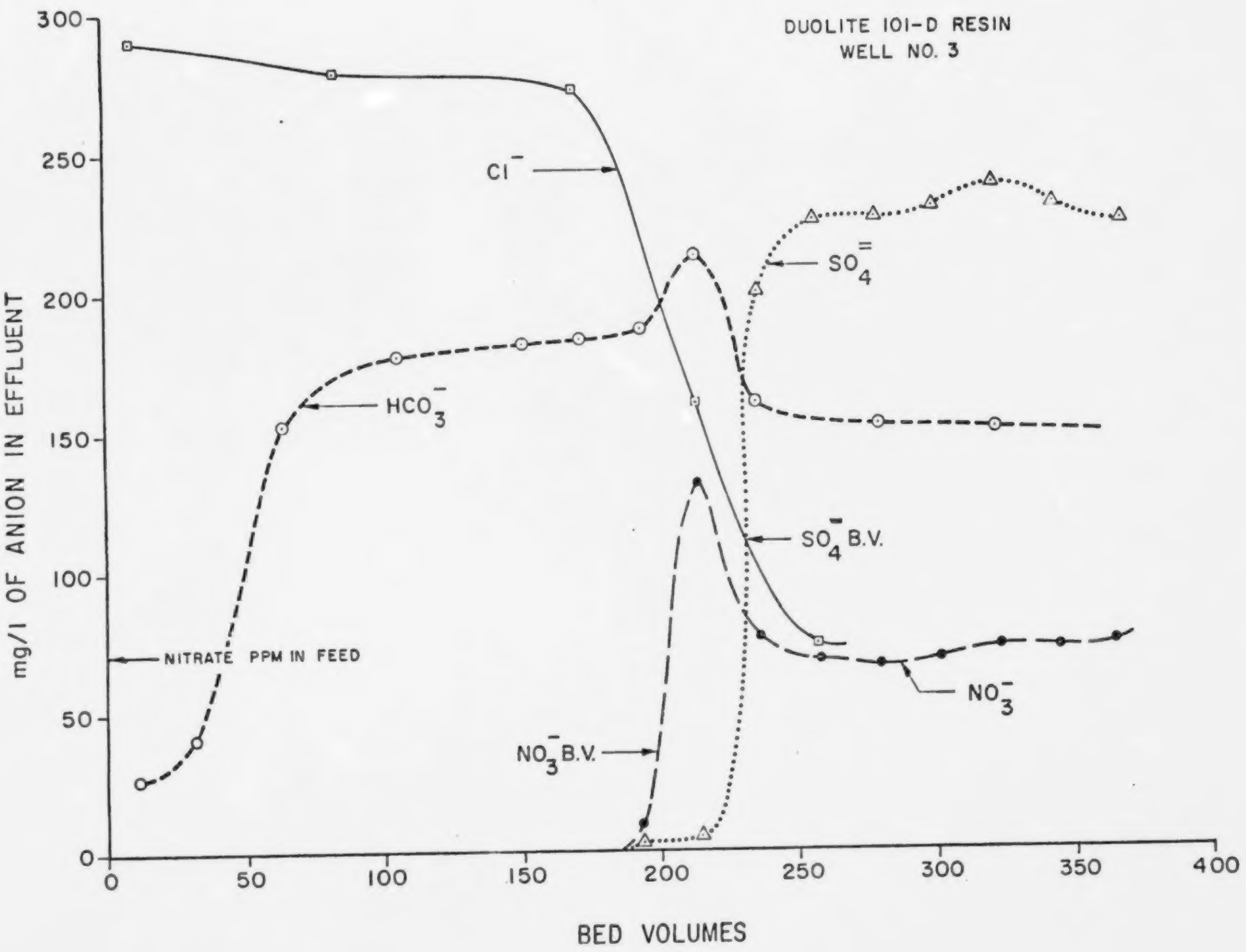

FIGURE 2 TYPICAL BREAK THROUGH CURVE

3. Brine Displacement. System water enters the bed to displace brine.

4. Slow Rinse. System water is used to rinse last traces of brine from resin.

5. Backwash/Resin Declassification. Fines are removed from top of bed and resin is mixed.

Under automatic control any combination of valve operation can be selected in one or more programs.

The resin declassification step is accomplished by a procedure similar to the backwash with bifurcated inlets.

Brine Disposal

An important consideration in locating the plant at Well Site 2 rather than Site 3 was the lower quantity of waste brine generated. Brine is disposed to the municipal waste treatment facility. Review by the City and the State Water Quality Control Board was done through the environmental impact report process. Because of the quantity of dissolved solids added to waste water concern was expressed for impact on soil and groundwater in the disposal area. Treated waste water is discharged to 128 acres of agricultural land used for growing animal feed grains and cotton.

The quantity of 6% waste brine discharged from Well 2 was estimated to be about 0.5% of the ion exchange plant production or 5,000 gallons per million gallons treated. If operated on a continuous 24 hour day without blending this would require 2500 lbs. of salt per day (raising TDS in the discharge area by about 600 mg/L). Had Well No. 3 been chosen for the demonstration plant 2 to 3 times this quantity of brine waste would be discharged per day.

A monitoring program was planned in the discharge area to monitor soil, groundwater and wastewater.

Automatic Operation

Automatic operation of the plant was considered essential to reduce the amount of manpower required to sustain continuous operation of the plant. Consequently, complete automatic operation was planned. This automation was extended to automatic monitoring and data collection. The only manual operations required were turning the system on or off and inspection of data and plant operation.

Monitoring of Performance

Because this was planned as a demonstration plant and operating costs and plant reliability were to be closely monitored extensive plant monitoring was incorporated into the design. The methods of flow and batch measurement presented no difficulty, however, the method of continuous nitrate monitoring was in doubt because of the lack of reliable methods. Ion chromatography was chosen as the method for testing since it appeared adaptable to continuous nitrate monitoring and had the capability to monitor other ions of interest. This is also an approved EPA nitrate method.

Planning for monitoring all flows and cycle changes was made. The monitoring and control were to be performed by a programmable controller which could also give alarms and printed reports of operation. Such extensive monitoring is not considered to be necessary for a standard plant.

Flow Diagram

A flow diagram is shown in Figure 3. Feed water is supplied directly from the well pump into two of the vessels in the service cycle. Vessel 1 being 50 percent exhausted when vessel 2 starts its service period.

When vessels 1 and 2 are in service No. 3 is in regeneration or standby. After No. 1 is exhausted 2 and 3 are in service, etc. Service is stopped in any one vessel by an electrical signal from a flow totalizer or by a manual signal.

The Brine Tank receives its water supply from system water supply. Backflow preventers are provided. Rinse water and backwash water are provided from treated water. Two proportionating valves serve to blend treated and untreated water.

Waste brine in any vessel is isolated from the main supply by "block-and-bleed" valves and check valves.

Electrical conductivity is monitored at well supply and product water locations to detect any brine leakage into supply. Alarm and shut down occur if product conductivity rises above that of supply water. Nitrate levels are also monitored in the blended supply and can cause automatic alarm and shut down.

DESIGN AND OPERATING PARAMETERS

Table 3 lists the bed characteristics and the target flow values used in vessel and piping design. The beds were sized to allow ample service time for regeneration of the standby bed. The service time

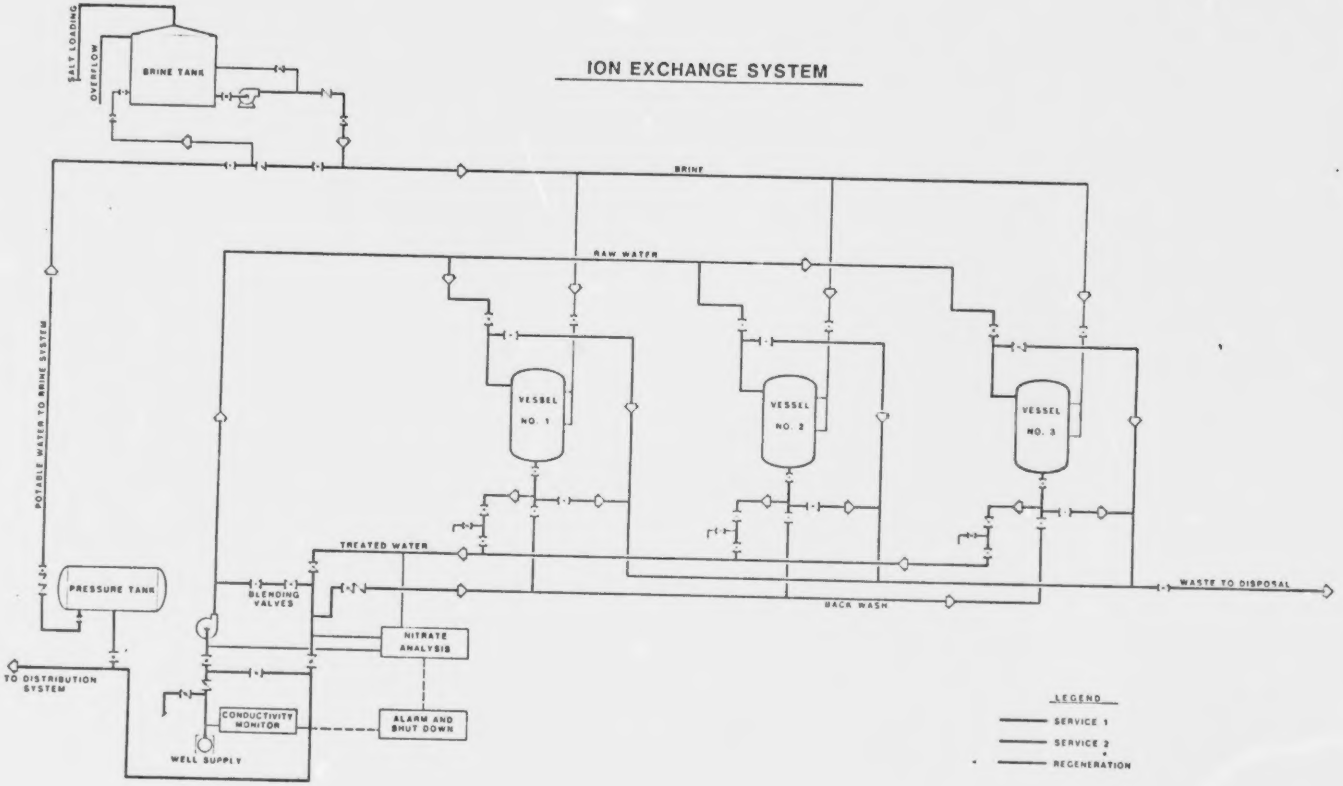
ION EXCHANGE SYSTEM
SALT LOADING
OVERFLOW
BRINE TANK
BRINE
RAW WATER
POTABLE WATER TO BRINE SYSTEM
VESSEL NO. 1
VESSEL NO. 2
VESSEL NO. 3
TREATED WATER
WASTE TO DISPOSAL
BACK WASH
PRESSURE TANK
BLENDING VALVES
NITRATE ANALYSIS
TO DISTRIBUTION SYSTEM
CONDUCTIVITY MONITOR
ALARM AND SHUT DOWN
WELL SUPPLY
LEGEND
SERVICE 1
SERVICE 2
REGENERATION

FIGURE 3. FLOW DIAGRAM

was estimated from the water quality (Reference 1) of the untreated water assuming a partially regenerated bed thoroughly declassified after regeneration and a nitrate leakage of 30 mg/l. Vessel height was designated to allow 100% expansion of the maximum bed depth to be used to allow for backwash.
during service.

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TABLE 3

BED CHARACTERISTICS AND TARGET FLOWS

Bed Cross Sec. Area = 27.7 sq. ft.

Bed Depth (Settled) = 36 in. to 60 in.

Bed Depth (Expanded) = 72 in. to 120 in.

Bed Volume = 85 cu. ft., 635.8 gal*

= to 142 cu. ft., 1059.7 gal.

Approx. Sat. Brine Con. = 2.6 lbs/gal.

Saturated Brine Rate = 12 gpm to 48 gpm

Brine Rinse Duration = 20 min.

Diluted Brine Rate = 63.5 gpm

BV of 6% Brine at above Parameters = 1.5

Slow Rinse Rate = 64 gpm to 110 gpm

Slow Rinse Duration = 30 to 60 min.

Backwash Rate = 5 gpm/sq. ft. = 140 gpm

Backwash Druation = 10 min.

Declassification Rate = Same as backwash

Declassification Duration and Procedure = To be determined by operator

Volume of resin in bottom header * = 21.85 cu. ft.

Volume of resin in straight height * = 57.3 cu. ft.

used for growing animal feed grains and cotton.

The quantity of 6% waste brine discharged from Well 2 was estimated to be about 0.5% of the ion exchange plant production or 5,000 gallons per million gallons treated. If operated on a continuous 24 hour day without blending this would require 2500 lbs. of salt per day (raising TDS in the discharge area by about 600 ppm). Had Well No. 3 been chosen for the demonstration plant 2 to 3 times this quantity of brine waste would be discharged per day.

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HEADWORKS

The lower left portion of Figure 3 shows flow and piping for the headworks. A general view of the plant is shown in Figure 4. The well pump (75 hp) is in the center foreground. The ion exchange vessels and the laboratory building are shown in the background. The main line from the plant is shown in the lower right corner as it enters the underground distribution system. The open pipe on the far right is an open discharge for flushing the well after long periods of inoperation. The valving of the headworks is not visible in this view.

The pump discharge line is shown in the foreground of Figure 5. Water leaving the pump enters the system through the check valve and the butterfly valve before entering the booster pump shown on the left in Figure 5. A butterfly valve to pass water directly to the distribution system is also shown in this view.

The 8-inch main supply line is shown in Figure 6 running from the plant to the underground distribution system. In this line a main shut-off valve, a water meter, two mercoid pressure switches and a shut-off valve to the plant are shown. The mercoid switches shut the plant down when distribution system pressure is high (over 65 psig). The second switch is a backup for the first. Power for the pump is restored five minutes after the pressure switches are activated by low pressure (55 psig). Also the booster pump is shown in this view in the upper right. Details between the booster pump and the ion exchange vessels are shown in Figure 7. Figure 7 shows the booster pump on the right with the steel discharge line joining the plastic 8-inch line with a flexible coupling. This line makes three right angle turns before entering the feed manifold to the vessels. A mercoid pressure switch and pressure gauge are connected into the plastic line. The mercoid pressure switch is activated at 100 psig to shut power to the pump off in case flow through the vessels produces a back pressure of 100 psig or more. Power is restored in this case by a push

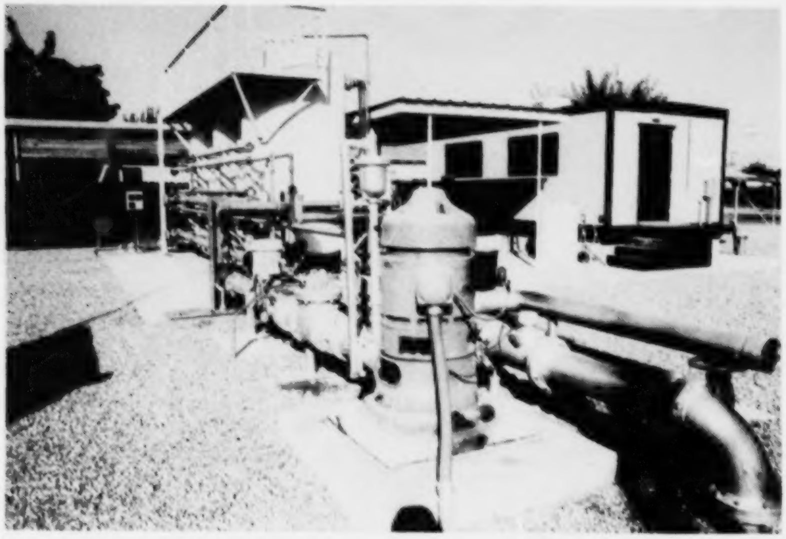


FIGURE 4. GENERAL VIEW OF PLANT

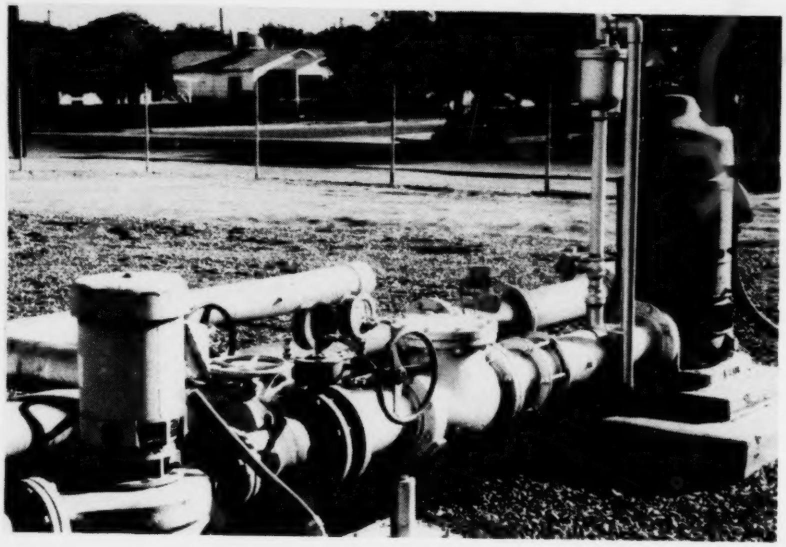


FIGURE 5. PUMP DISCHARGE PIPING

button switch on the power panel. In this view the distribution line from the plant is shown in the center of the picture crossing from left to right. A motor driven butterfly valve is shown in the center of Figure 7. This valve can by-pass water from the booster pump directly to the distribution line and can be automatically operated on signals from the microprocessor. These signals in turn are controlled by nitrate levels of the well and product water from the ion exchange vessels. A wash water line is seen coming from the distribution main and running to the wash water manifold to the left of the picture.

Figure 8 is a close-up view of the motor operated by-pass valve. The distribution line is in the foreground, the booster pump discharge line is in the background. The ion exchange vessels are out of view to the right of the picture and the pumps are out of view to the left. The backwash and rinse water line is shown at the top.

Figure 9 shows most of the above features in a general view. The motor operated valve is in the center of the picture. The pump discharge line can be seen running from the booster pump to the vessels on the right through the line with three right angle turns. The main distribution line runs from the vessels on the right without any bends to the left. On the right side of the picture a meter box can be seen which houses flow meters for wash water, treated water, and backwash water. The brine tank can be seen in the left background.

ION EXCHANGE VESSELS

As shown in the flow diagram (Figure 3) three ion exchange vessels of equal design contain the resin beds and the appropriate valving. The vessels have a straight side height of ten feet to accomodate resin beds of up to five feet deep to allow for 100 percent expansion on backflush. Figure 10 is a general view of the vessels showing the feed water, product water, and wash water manifolds on the far left, the vessels with a control panel on each, protective canopy and concrete pads. The vessels are placed on a concrete pad 10'x30'x12". The utility pad between the vessels and the laboratory building is 30'x30'x2".

Figure 11 is a close-up view of the upstream side of vessel No. 1. Two pipes are seen on the left side of the vessel branching from the manifolds. The upper 4-inch pipe is the feed water supply and contains a batch meter. The lower pipe is the backwash water supply. The "Z" shaped pipe parallel with the left front leg is the product exit pipe from the vessel.

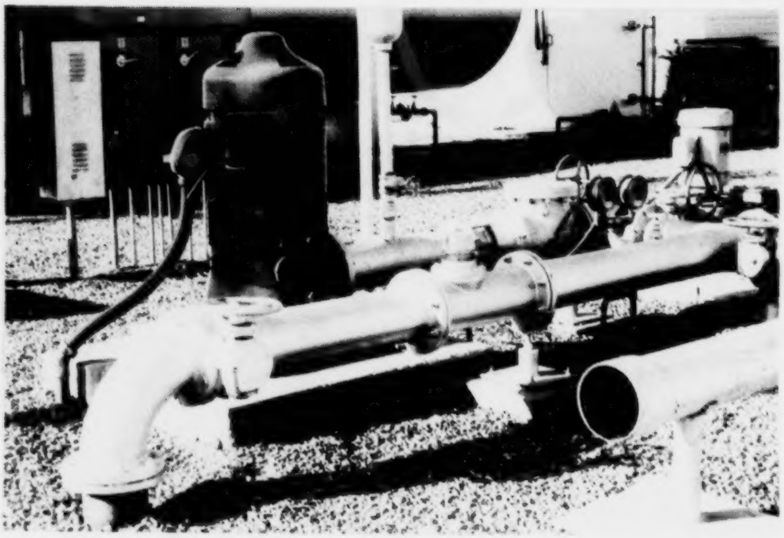


FIGURE 6. PIPING TO DISTRIBUTION SYSTEM

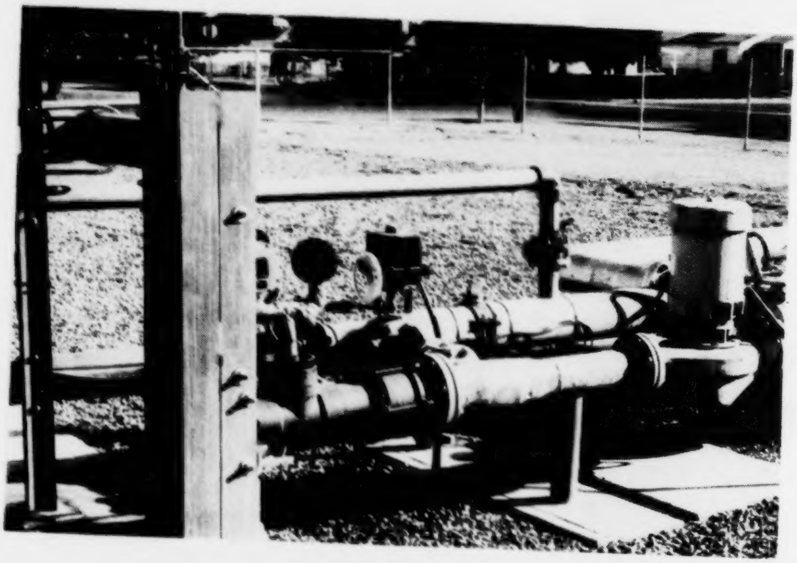


FIGURE 7. DISCHARGE FROM BOOSTER PUMP

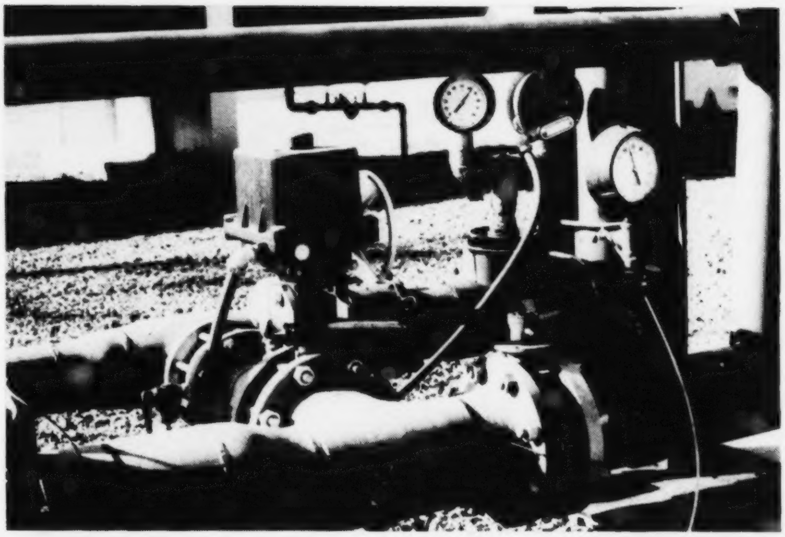


FIGURE 8. MOTOR OPERATED BLENDING VALVE

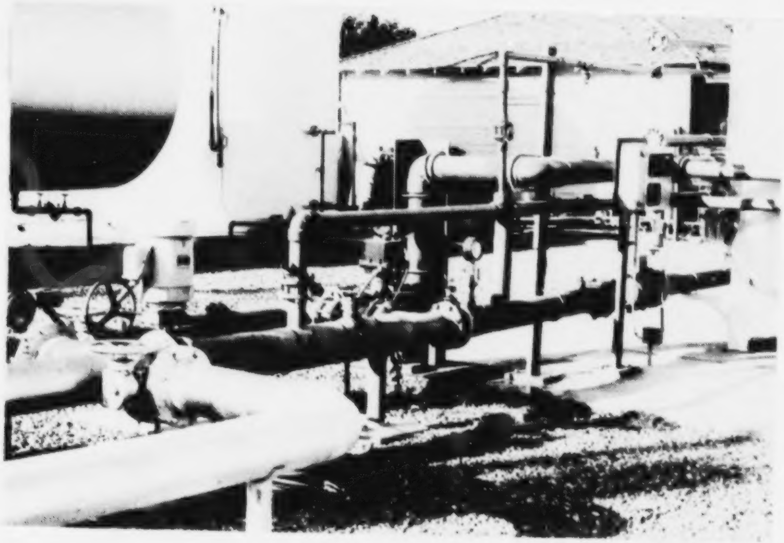


FIGURE 9. GENERAL VIEW OF HEADWORKS PIPING

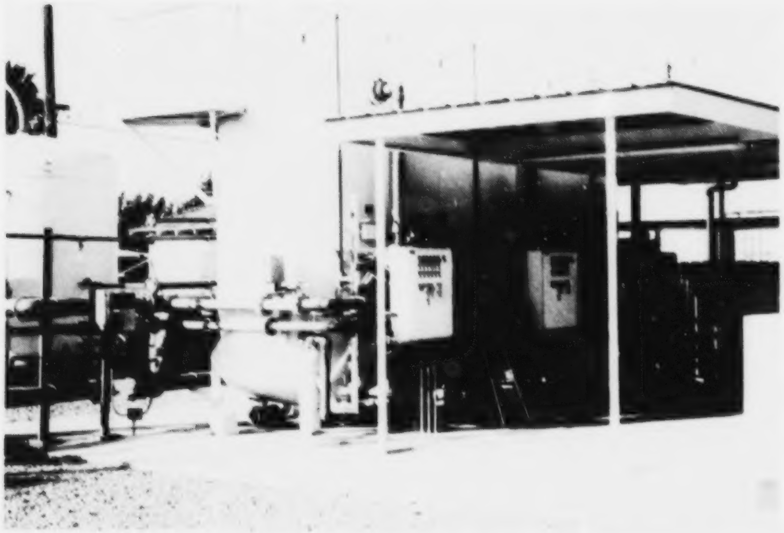


FIGURE 10. FRONT OF ION EXCHANGE VESSELS

Figure 12 is a view of the right hand side of vessel No. 3. The control panel is on the left in front of the feed water pipe and the backwash valve and pipe. On the right of the vessel various pipes run from the manifolds in the back to the front of the vessel. These pipes from top down are: a 1-inch brine line and automatic valve, a 1-inch slow rinse line, a 3-inch backwash exit line. The lowest line is the 4-inch product line containing two automatically operated valves. The waste discharge lines are shown in the lower right over the grating of the waste collector box.

Figure 13 is a view of the rear of the vessels with the pumps and headworks on the right. The various manifolds connected to each vessel are from the top down are:

1.	Brine inlet	1"
2.	Slow rinse inlet	1"
3.	Wash water and brine exit	3"
4.	Feed water inlet	6"
5.	Wash water inlet	3"
6.	Product water line	6"

VESSEL INTERNALS

The internal piping of the ion exchange vessels is represented by the drawing in Figure 14. The internal elements can be identified by the outlet number. The drawing also gives the dimensions measured from the top of the base of the center hub of the bottom drain. No. 1 is the brine distributor. As shown it is positioned to deliver brine six inches above a three foot deep resin bed. Rotation of the distributor 180 degrees about the inlet axis positions the distributor for a five foot deep bed. Nos. 2 and 4 are the drain outlets which drain product water from each half of the spoked collector, No. 5. Element No. 3 is the feed water distributor. Not shown on this drawing are the various openings in the side of the vessel to accomodate samplers and other devices which may be desired in the future.

BRINE SYSTEM

Piping for the brine system is shown in the upper left of the flow diagram (Figure 3) and in Figure 15. Water is added to the brine tank directly from the system via the 1.5-inch pipe shown at the left in the picture emerging from underground running to near the center and upward into the brine tank inlet (not shown). Flow into the tank is controlled by an electrically operated valve and can be activated from level

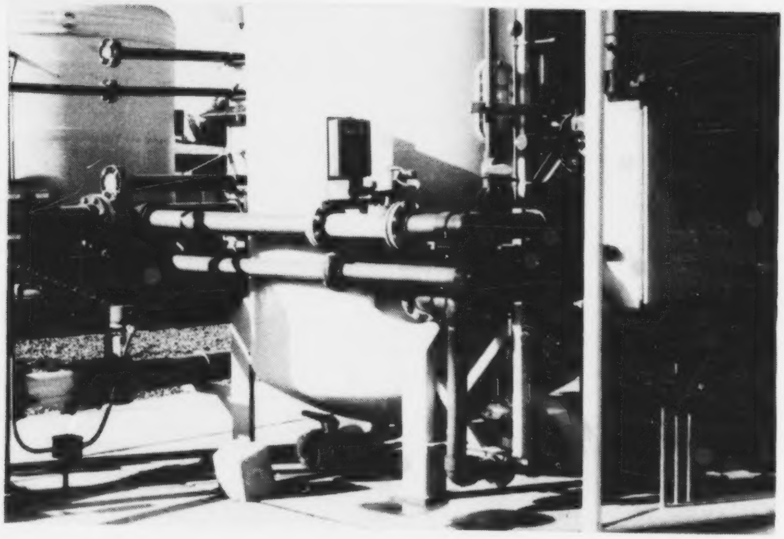


FIGURE 11. VESSEL PIPING - LEFT SIDE

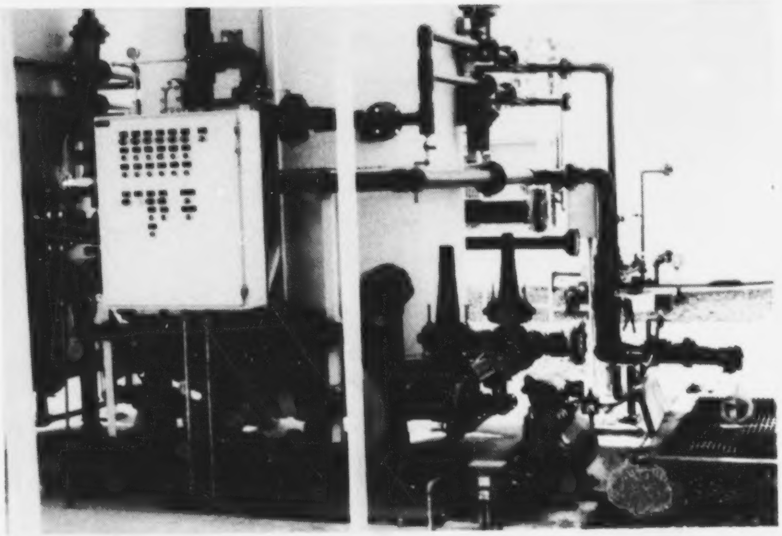


FIGURE 12. VESSEL PIPING - RIGHT SIDE

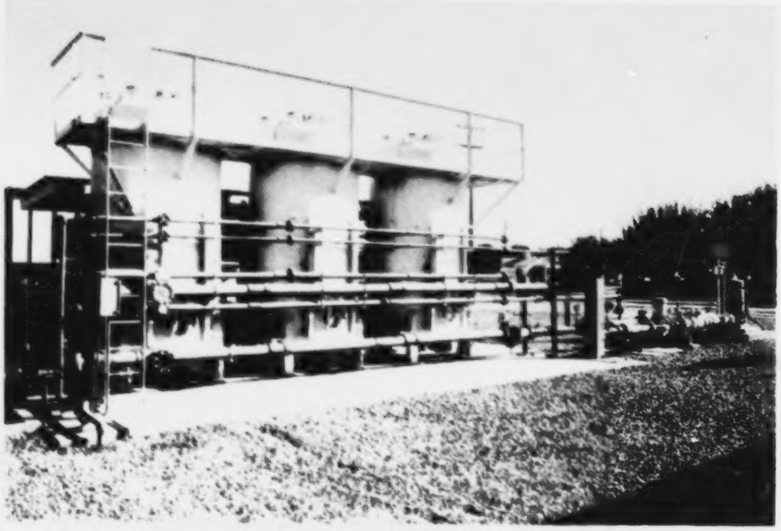


FIGURE 13. REAR VIEW OF ION EXCHANGE VESSELS

NOTE: DIMENSIONS FROM TOP
OF BASE PLATE

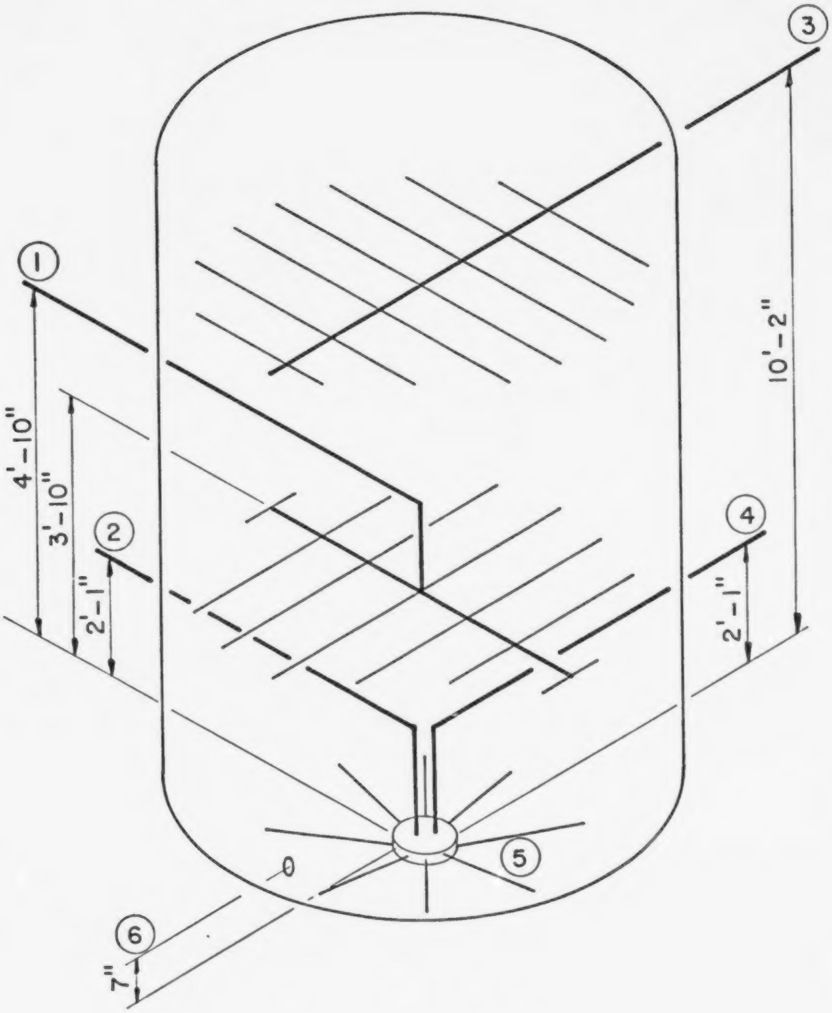
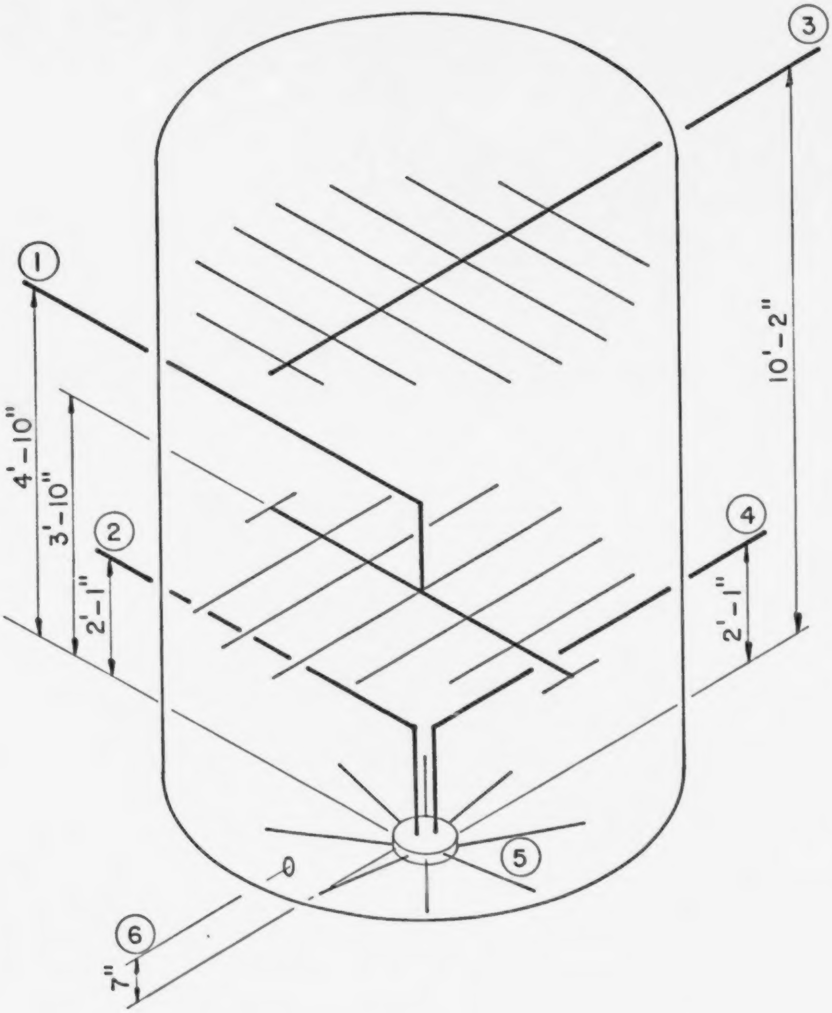

③
①
10'-2"
4'-10"
3'-10"
②
④
2'-1"
2'-1"
⑤
0
⑥
7"

FIGURE 14. INTERNALS OF ION EXCHANGE VESSELS

NOTE: DIMENSIONS FROM TOP
OF BASE PLATE



③
①
10'-2"
4'-10"
3'-10"
②
④
2'-1"
2'-1"
⑤
⑥
7"

FIGURE 14. INTERNALS OF ION EXCHANGE VESSELS

sensors or can be operated manually from the main control panel. Liquid level in the tank can easily be observed with a 2-inch diameter sight glass. The latter means of control was used during this period of operation since an operator made frequent visits to the site.

The outlet of the brine tank can be seen in the upper portion of the picture. Concentrated brine is drawn through this 2-inch pipe by the small centrifugal pump shown. Brine is pumped through the 1-inch piping on the right through a check valve and an electrically operated solenoid valve. The latter was added after failure of the check valve to close on several occasions. The electric valve is powered by the same circuit supplying power to the brine pump.

Concentrated brine is blended with water by the piping shown in the foreground before it enters the underground pipe feeding the brine systems of the vessels. Diluting the brine was felt to favor the discharge of waste brine to the local sewer system and to prevent resin deterorization by osmotic shock.

PRODUCT DELIVERY SYSTEM

The product delivery system is shown in the above figures showing the vessel manifolding and headworks. Product is collected from each of the operating vessels and allowed to flow directly into the distribution main. The product can be blended with untreated water using the blending valves provided. Blending can be controlled by automatic means through the microprocessor or manually at the discretion of the operator.

PROCESS CONTROL

Manual Control

Due to the research nature of this program it was decided to provide for manual operation of the plant to work out an algorithm for the microprocessor program. This was especially desireable since the process employed was new. Furthermore, resin declassification had not been previously employed in a system of this type and valving sequences had to be laboriously determined by a trial and error method. Furthermore, this allowed the plant to be placed into operation before all automatic devices including the microprocessor and main control panel had been completed. The wisdom of this choice became more obvious when it was found what trouble and expense were involved in programming and testing the microprocessor control

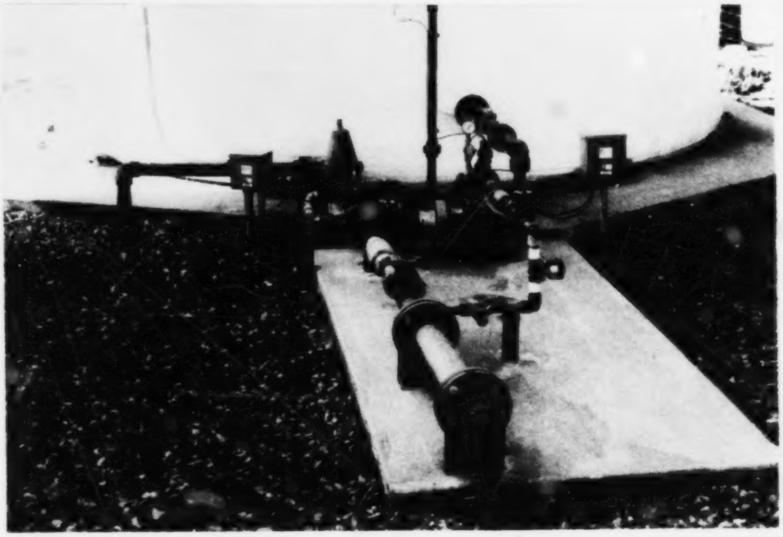


FIGURE 15. BRINE SYSTEM PIPING

system. The approach here was to work out in as much detail as possible the program by trial and error testing under manual control; then write the computer program accordingly.

Manual operation was accomplished by controlling the valves on each vessel from the push button control panels. Flow quantities were measured by several meters and flow rates were adjustable by hand valves except for service flow rate which was only adjustable by blending.

Service flow was metered by batch reset meters on each vessel. Figure 16 is a view of the batch reset meter in the feed water line to vessel No. 1. A pulsed signal is sent to the box above the meter which advances the register in the small box shown directly above the meter. When the registered gallonage equals a preset quantity an end-of-batch signal is sent to the control panel. A red light indicates to the operator that the vessel needs regeneration. A wiring option inside the control panel also allows the signal to take the vessel out of operation. The regeneration cycle for the vessel can be completely controlled from the panel. Figure 17 shows the meters which measure the amount of concentrated brine, dilute brine and make-up water for brine. Figure 18 shows meters for total treated water, backwash water, and rinse water. After brine, rinse, and backwash are completed the vessel can be placed in stand-by or into service.

SEMI-AUTOMATIC OPERATION

After flow rates are adjusted the regeneration of each vessel may be performed by an automatic timer/sequencer which was installed in each control panel. These timers were of the type used for controlling irrigation systems (Rain Bird Model CRC-8). The operator was required to initiate the regeneration cycle and place the vessel into operation when required. This required the operator to make frequent checks or estimate the end of service for the next vessel.

AUTOMATIC OPERATION

Automatic process control is accomplished with a TI-500 microprocessor manufactured by Texas Instruments and the inputs from the flow meters, conductivity sensors, and the nitrate analyzer. Figure 19 shows the main control panel which houses the process controller and into which all of the control signals are sent and some of which are displayed. Nitrate levels are recorded by the top recorder. Electrical conductivity of well and product water are both recorded on the bottom chart. The light box annunciator on the top right

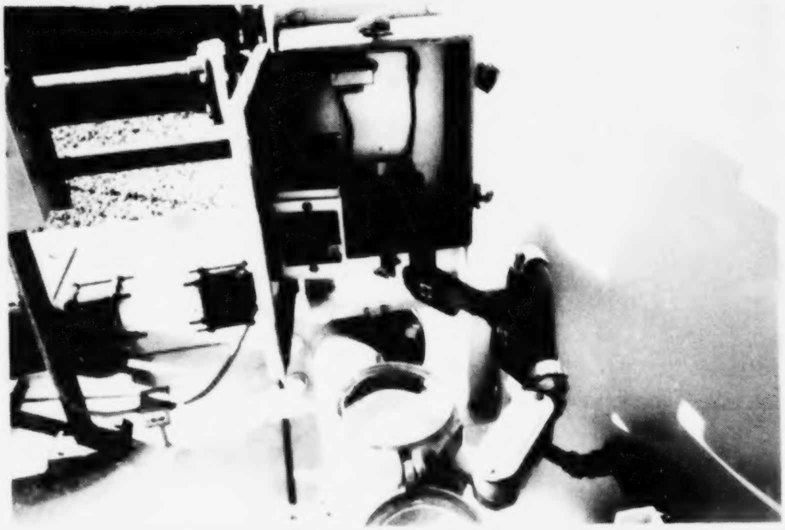


FIGURE 16. BATCH RESET METERS

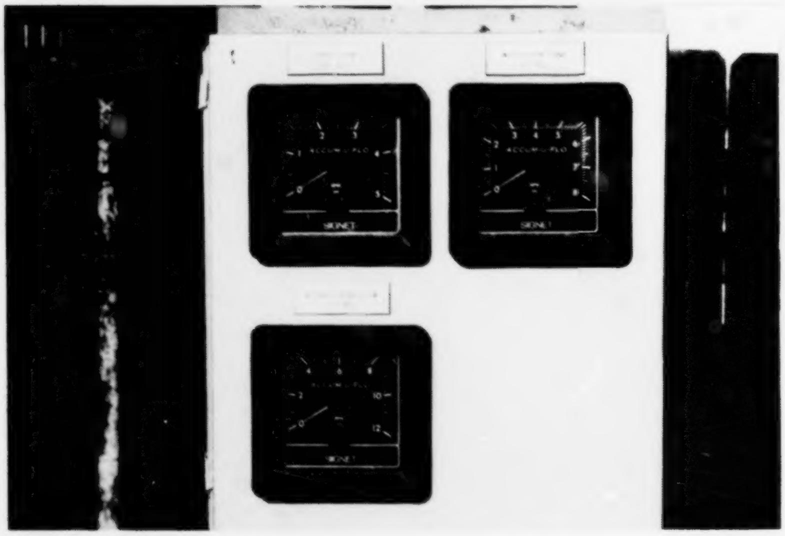

ACCUMU-FLO
SIGNET
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FIGURE 17. BRINE AND MAKEUP FLOW METERS

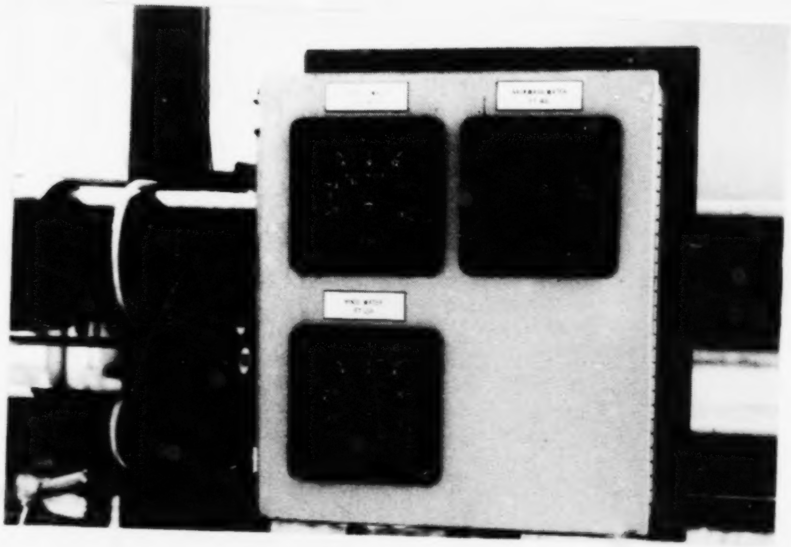


FIGURE 18. TREATED, BACKWASH, AND RINSE WATER FLOW METERS

displays the status of each vessel and pumps. Conductivity of waste water, well water, and treated water are displayed in the three read-outs below the annunciator. Two read-outs above the switches give total water delivered and treated. The switches turn on the microprocessor, select the vessel sequence, control water to the brine tank, and reset after alarm. The printer gives a daily report of all flows, nitrate levels, conductivities, status of each vessel, and alarm conditions. Reports are also printed at any time on demand and are automatically given for alarm conditions: high nitrate, high conductivity in product and power failure.

Figure 20 shows the interior of the control panel. The microprocessor sequencer and power supply are the two white boxes on the right side. The input modules are on the left. Wire terminals are on the bottom. The small box near the sequencer is for inputting numbers to the microprocessor such as brine dosage and service batch used in the control program or in the calculations for the report.

Figure 21 shows the ion chromatograph used for nitrate monitoring. The unit shown is a dual unit. One is dedicated to nitrate measurement of treated or blended water. The other unit is used for research purposes. A signal of nitrate level goes directly to the control panel. The upper left compartment is the chromatography unit. The pump modules are on the lower bottom. The upper right houses the conductivity meters; the automatic controller is below these.

Figure 22 shows the interior of the 12'x24' building being used as both laboratory and control room for the plant. The ion chromatograph is shown center right. The enclosure behind the instrument contains a store of distilled water and other liquid solutions for the operation of the analyzer.

Figure 23 shows the interior of the other end of the building with the above described control panel to the right of the door.

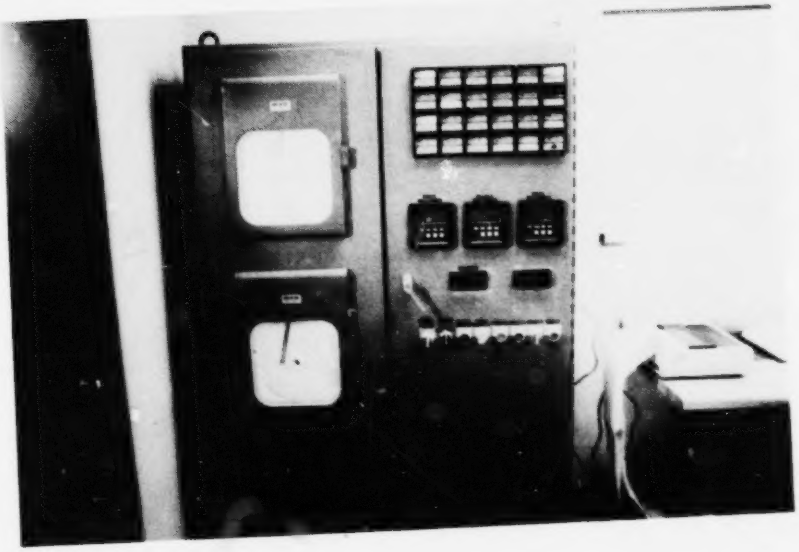


FIGURE 19. MAIN CONTROL PANEL

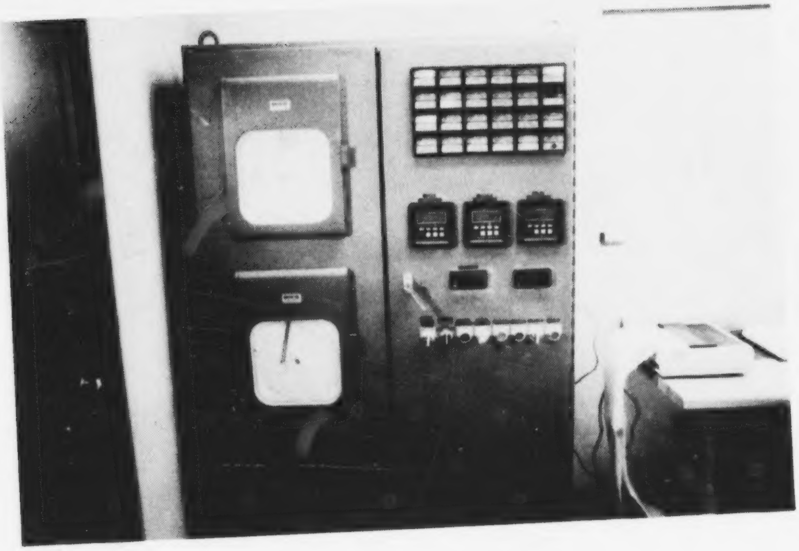


FIGURE 19. MAIN CONTROL PANEL

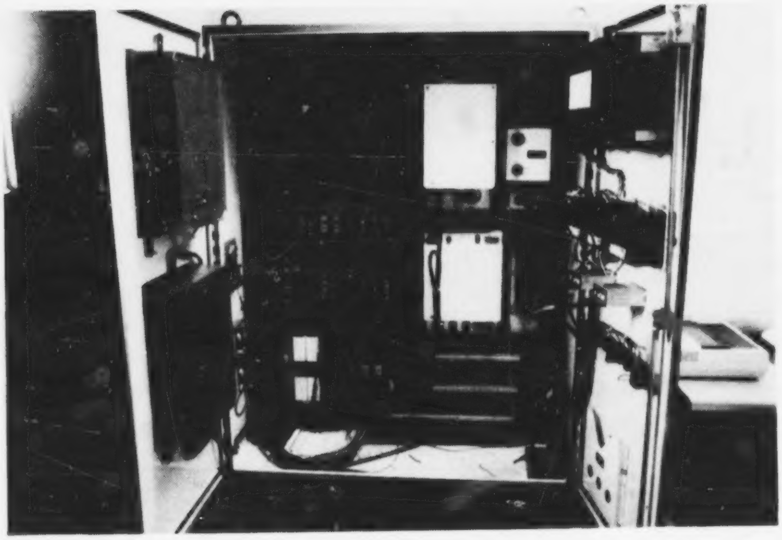


FIGURE 20. MAIN CONTROL PANEL INTERIOR

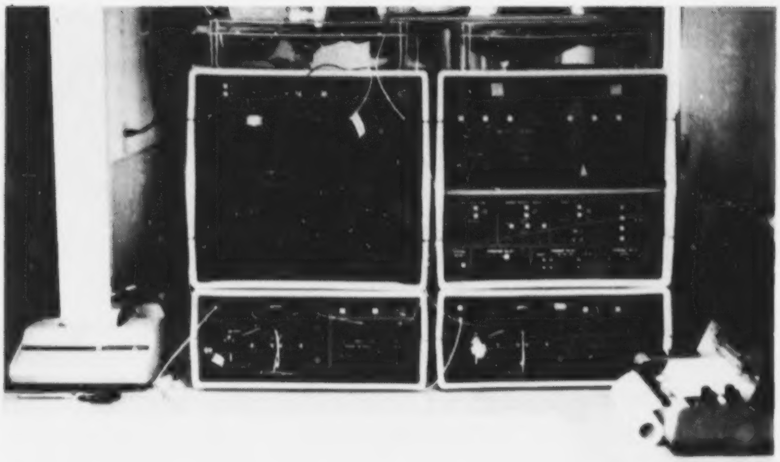


FIGURE 21. ION CHROMATOGRAPH

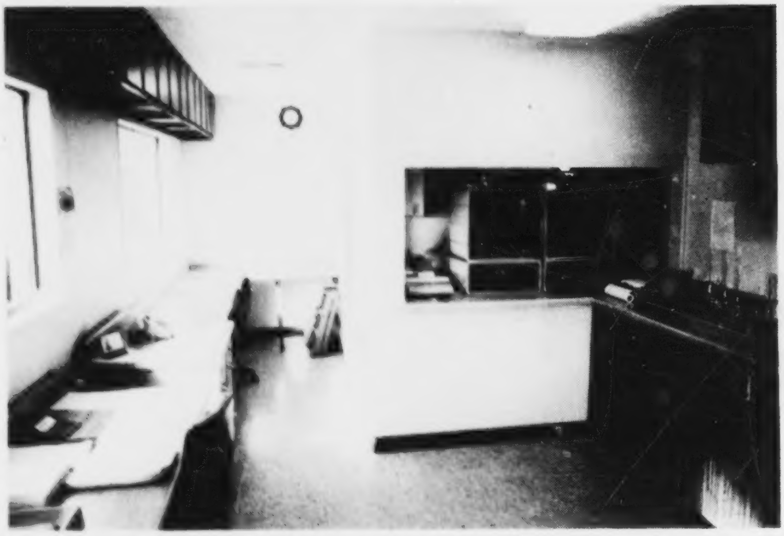


FIGURE 22. LABORATORY AND CONTROL BUILDING INTERIOR WEST SIDE

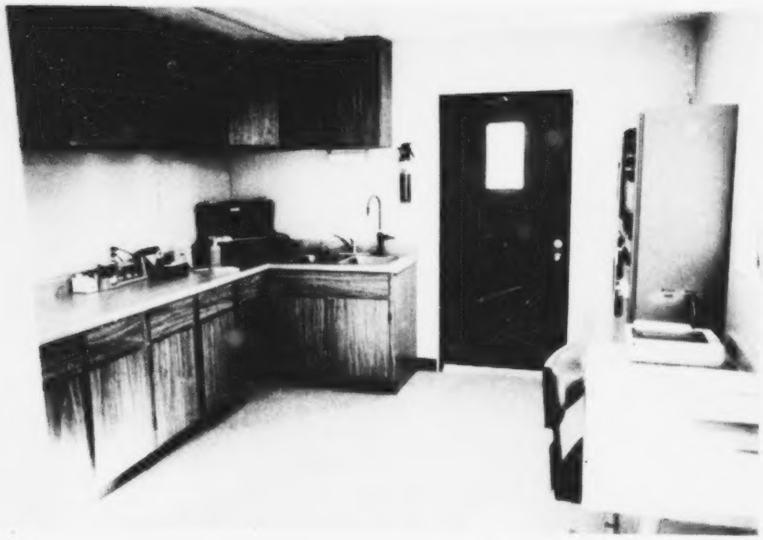


FIGURE 23. LABORATORY AND CONTROL BUILDING INTERIOR EAST SIDE

SECTION 4

PLANT OPERATION

CHECK OUT AND START UP

Resin Purchases and Loading

Resin was purchased with funds provided by the EPA, Kern County Water Agency and McFarland Mutual Water Company. The resin purchased was Duolite A-101D and was sufficient for the initial three foot bed depth (225 cubic feet) plus the additional two feet of bed depth (170 cubic feet) and 50 cubic feet as make up resin. All resin was purchased at one time to avoid future price increases. See Table 4.

TABLE 4

RESIN PURCHASES

Order No.	Quantity	Price	Agency
1	18 cu. ft.	$ 2,371.68	McMWCo.
1	237 cu. ft.	31,227.12	KCWA & McMWCo.
2	170 cu. ft.	22,399.20	EPA
2	50 cu. ft.	6,588.00	EPA

The purchase price of the resin was $124.30 per cu. ft. plus $7.46 sales tax. Prices include delivery to the job site.

The resin was ordered and delivered in drums each containing five cubic feet. Handling drums for unloading or loading into vessels requires five men, one of which operated a fork lift.

To load the vessels, a temporary wooden frame was constructed on top of the vessels being loaded to allow the drum to be rolled over the top manhole. Two men positioned the drum onto the fork lift which was operated to place the drum near the frame. Two men on the cat walk placed the drum on the frame and rolled it over the open manhole and opened the drum and plastic bag to let the resin fall into the vessel. The vessel was partially filled with water to prevent damage to the resin as it fell into place.

This operation required one hour to load fifteen drums (85 cu. ft.) into each vessel.

Salt Delivery

Salt was delivered to the site approximately one week after placing the order with a local distributor. The delivered price was $31.50 per ton. A load of 25 tons was transported from the San Francisco Bay area. Salt unloading required approximately one hour. The only labor required was provided by the driver and his cost was included in the delivery cost.

Plant Check Out

Prior to resin installation the ion exchange vessels and plumbing were pressurized to check plumbing leaks and valve operation. Testing continued after resin was installed. The following malfunctions were noted:

1. Automatic valve closures were found to be too rapid in some cases and caused water hammer pressure rises within the system. These were adjusted.

2. The intergrating flow meter on Unit 1 could not be reset. This was replaced.

3. Some flow meter sensors were malfunctioning. Readings of treated water flow rates were off by a factor of .7 according to other flow meters in the system. This flow sensor was replaced.

4. Plumbing leaks were noted in the manifold lines and brine tank plumbing. None were serious.

5. It was noted that when all three vessels were in service at low flow rates (approximately 100 gpm each) the flow channeled through only two of the vessels and stopped in the third. This is not a malfunction and can be expected at low rates. No operational mode will require this type of operation.

6. Pump discharge pressure appeared to be higher than expected. This was thought to be due to a rise in ground water level over the previous year. This has caused high pressure build up on the inlet side of the vessels and breaking and severe leaking from the quick connect plastic caps (3-inch) on the top of each vessel. These caps were replaced with aluminum caps. They were eventually replaced with blind flanges. Pressure drop across the ion exchange vessels was

approximately 10 psi.

7. On backwash with resin installed the filter in the backwash discharge line was immediately clogged with resin fines. This filter was removed and the backwash was allowed to flow through a 50 mesh screen and into the sump to catch the fines. It was noted that approximately 300 ml of fines were recovered on each of the initial backwashes. These fines were eventually washed from the system and were reduced to zero.

8. The pressure limiting switches were not functioning to allow automatic well pump control at low and high distribution system pressure. These switches were faulty and recommendations were made to replace them with Mercoid switches which were found to be very reliable. Manual pump on-off control was reuqired until these limiting switches were replaced.

Resin Washing

After the resin tanks were loaded and sealed each bed was washed with water available from the distribution system. The resin manufacturer recommended either washing or chemical treatment to exchange all ions in the resin. The washing method was preferred to save chemical costs and disposal problems and because of the availablility of a plentiful water supply. If sulfuric acid were used for this operation, approximately 75 gallons of concentrated acid and 1300 pounds of sodium chloride would be required for one complete ion exchange. The number of ion exchanges required was not known. It was decided to try the washing method first.

The washing method was accomplished by leaving the well pump off and placing each unit in slow rinse. In this manner each bed could be rinsed at a rate of approximately 50 gpm (0.08 BV per min). However, it was found that only two vessels could be rinsed simultaneously in this manner. Slow rinsing was recommended by the manufacturer since both rinsing time and quantity of water are required to remove the excess trimethyl amine from the interior of the resin beads. Approximately 300,000 gals (470 BV) of water were required to eliminate the taste and odor of trimethyl amine in the rinse water for each bed. This operation required approximately 100 hours for two vessels and an additional 100 hours for the third vessel.

The water used for rinsing was the water which happened to be in the distribution system. Wells No. 6 and 1 were in use at the time. A chemical anaylsis of the entering and leaving waters were obtained. See Table 5. The total anion content of the wash water was 2.7 meq/l. Consequently it appears that approximately one ionic equivalent is required per volume of resin for the resin conditioning. (1300 meg/l divided by 2.7 meq/l = 481 BV) As pointed out above, 470 BV were used.

TABLE 5

WASH WATER COMPOSITION

Constituent	Milligrams Per Liter	
	In	Out
Carbonate	13.6	0
Bicarbonate	38.1	36.6
Chloride	23.0	74.4
Sulfate	50	5
Nitrate	2.8 mg NO3-N/L or 12.4 mg NO3/L	Less than .1 NO3-N/L or .4 mg NO3/L
Arsenic	0.04	Less or . 0.01
pH	9.2	7.8

The arsenic in wash water was from Well No. 6. The nitrate was from Well No. 1. It is interesting that the resin was very effective in removing the arsenic as well as the nitrate and had the added advantage of reducing the pH to a desirable level. Well No. 6 arsenic levels have been found to be as high as 120 micrograms per liter and the pH is well over 9.

The above analysis was taken at a BV throughput of 405 BV. If arsenic is being removed as a divalent anion, probably HAs O = at pH9 it is expected to treat Well No. 6 water and obtain over 800 BV of arsenic free water per service cycle.

Initial Regeneration and Washing

Before automatic operation was initiated it was necessary to test performance using the operational parameters, some of which are given in Table 3. These include flow rates, pressures, duration of wash and backwash, method of resin declassification, breakthrough characteristics, and water quality parameters. These studies could best be done while operating one vessel at a time. This also allowed the establishment of methods of manual operation which may be necessary or useful at times in the future. Each vessel was prepared for one-at-a-time operation by regenerating each bed with 1.5 BV of 6% brine (or equivalent) to remove sulfate, arsenic, and sulfate accumulated during the initial washing.

Sample ports are located at the same positions in the center of each bed. The location of each port in relation to the upper resin surface is given in Table 6.

TABLE 6

POSITION OF SAMPLE PORTS

Port No.	Inches Below Resin Surface	% Into Bed
6	(15 inches above surface)	
5	(6 inches above surface)	
4	1	2.72
3	7	19.01
2	14	38.02
1	28	76.04
0*	36	100.00

* Port 0 is same as vessel outlet.

The initial regenerations were accomplished with some deviation from the above target values. It was found that diluted brine rates varied from 22 to 36 gpm with the result of using a more concentrated brine than expected. This was due to a flow restriction valve in the waste brine exhaust. This was repaired. The effect was to require more slow rinsing than expected. Rinse duration was 60 minutes and used up to 3990 gallons (6.3 BV). Table 7 shows the drop in TDS of the wash water throughout.

TABLE 7

TDS OF WASH WATER

Sample	TDS	Gallons	BV
Fresh brine	150,000	0	0
15 min	4,000	960	1.51
30 min	800	2020	3.17
45 min	600	3000	4.72
60 min	474	3990	6.27

Lesser wash water quantities were used as fresh brine concentration was reduced to 6%.

Initial Column Exhaustions

The columns were exhausted one at a time with Well 2 water. The main by-pass valve (rather than the blending valve) was used to by-pass part of the pumped water. The plant was started using the following procedure:

1. Well pump OFF
2. Power to selected vessel turned ON
3. Control switch set to MANUAL
4. Service switch turned ON
5. Main by-pass valve opened full to by-pass plant
6. Turn well pump ON
7. Partially close by-pass valve until desired flow rate through vessel is achieved.
8. Readjust by-pass valve until desired ratio of treated to untreated water is achieved.

The plant was then allowed to run while monitoring nitrate levels in the various sample ports until the nitrate level reached 30 mg/l in the effluent. At this point the following shut down procedure was employed:

1. Well pump shut OFF
2. Power to vessel turned OFF
3. Regeneration switch turned ON
4. Allow vessel to remain in stand-by until start of regeneration.

NOTE: It is important to shut well pump off before turning vessel OFF to avoid high pressure surges into the vessels.

The next vessel was placed into operation with the following procedure.

1. Power to vessel turned ON
2. Control switch set to MANUAL
3. Control switch set to SERVICE

4. Well pump turned ON

5. Adjust by-pass valve if required to obtain desired blend

A chemical analysis of untreated, treated and blended water was obtained from a certified laboratory. The results are given in Table 8.

TABLE 8

CHEMICAL ANALYSES FOR INITIAL RUNS

Constituent (mg/l)	Untreated	Treated	Blend
Calcium	94	98	96
Magnesium	2.1	2.1	2.1
Sodium	68	68	68
Potassium	3.8	3.6	3.8
Bicarbonate	119	27.7	120
Chloride	88.2	264	166
Sulfate	120	less than 5	40
NO3-N/L	16.0	2.6	6.6
NO3/L mg	70.9	11.5 mg	29.2
Color Units	1	1	1
Odor	none	none	none
pH	7.2	7.4	7.4
EC, micromhos	790	920	850

DECLASSIFICATION TESTS AND MANUAL OPERATION

The ion exchange plant was operated manually using one vessel at a time at the approximate flow rates described above. Tests were performed by reducing the amount of brine dosage for each subsequent regeneration until a significant nitrate leakage was obtained. Salt dosage equivalent to one BV of 6% brine gave significant nitrate leakages to test the resin declassification system. Subsequent runs were then made at that dosage while changing the declassification cycle parameters.

The method of declassification which appears to be most effective is to backwash with only one of the two (V-106 and V-107) backwash inlet valves open for a three minute period and then closing for a three minute period to allow the bed to fall. This sequence is then repeated a number of times to further mix the resin. The effectiveness of the operation can be assessed from the shape of the breakthrough curve taken during the

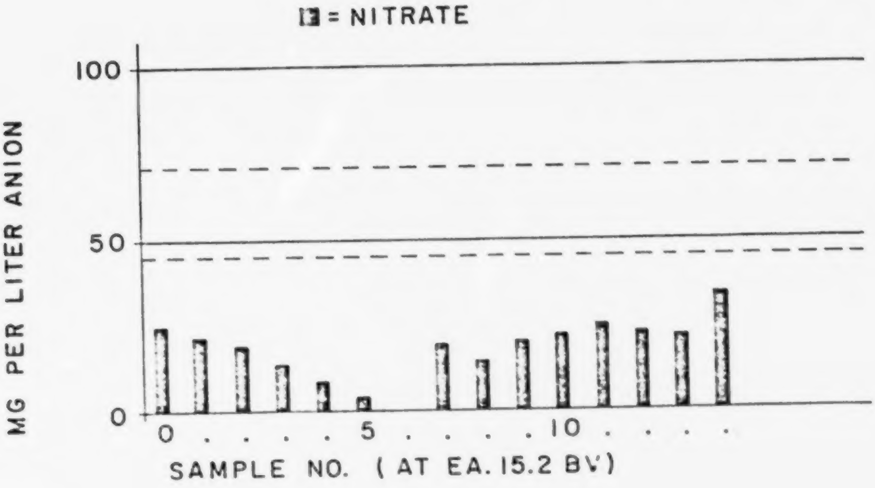


FIGURE 24. RUN NO. 01114-P3

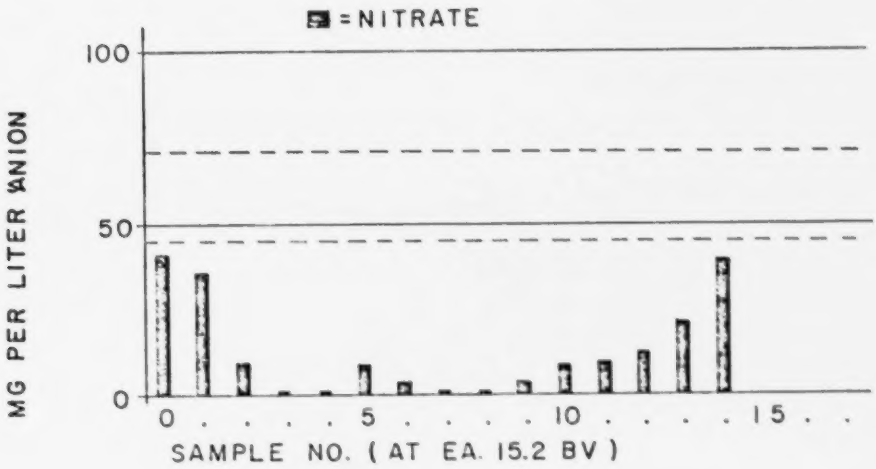


FIGURE 25. RUN NO. 12143-P1

subsequent run.

The data for each run was entered and analyzed by a spread sheet program. Graphs of the breakthrough curves were also obtained from the spread sheet data. The breakthrough curves are given in bar chart form. These typical spreadsheets and charts are given in Tables 9 and 10 and Figures 24 and 25. These represent the best and worst cases respectively. The analysis of all test runs is listed in Table 11.

The first three runs listed in Table 11 were regenerated after the initial resin washing with system water which contained nitrate. The beds were not fully exhausted with sulfate or nitrate. Although both halves of each bed were backwashed separately, poor mixing resulted as seen in the corresponding breakthrough curves. The experiments continued with a series of regeneration/exhaustion cycles starting at high salt loading and decreasing by 0.5 BV (6%) on subsequent runs. The reason being to achieve a high nitrate leakage where sensitivity to declassification is greatest. It was found the system could be operated using only one 1.0 BV (6%) regenerant. With no attempt to mix resin very poor results were achieved in run 12143-P1. Subsequent runs showed gradual improvement. It is apparent from the results that simple backwashing does not mix the resin sufficiently even if only one backwash valve is used.

That the intermittant on-off cycling is effective indicates resin is missed during the start (or stop) of the uneven backwash period. At the beginning the bed is not fully fluidized and resin aggitation is quite obvious as viewed through the sight glass. At the end of the cycle the upper portion (chloride enriched) of unfludized bed may redistribute itself on the bottom of the bed before the fludized portion of the bed falls to compact thus achieving an overall redistribution of resin in the beds (and chloride enrichment at the bottom of the bed).

ANALYSIS OF INITIAL OPERATION

The data of the above runs provides the initial opportunity to compare actual with estimated plant performance as far as salt usage is concerned. All data from the breakthrough curves were entered on spread sheets and regeneration efficiencies obtained from the calculations within the spread sheet. A summary of important performance data is given in Table 12.

The estimates of nitrate leakage and BV(N) were made using the method developed and reported under the previous grant. (Reference 1) In general nitrate leakages are considerably lower than the estimates and actual BV(N) values are 10 to 15 percent lower than estimated.

The latter may be due to stopping the run prematurely at 30 mg/l and not taking into account the resin capacity expenditures during washing. Approximately 4.5 BV washing were used in the slow rinse cycle. The lower leakages and shorter bed life translates into a considerably higher salt efficiency than expected from the estimates. The nitrate removal efficiency is about 75% higher than expected as indicated by the data in colum 7 of Table 12 for the runs using only 1.0 BV (6%) regenerant.

A further indication of salt efficiency and effectiveness of partial regeneration is the ratio of the equivalents of chloride used per equivalent of nitrate removed (Brine Use Factor). This data is summarized in Table 13.

The higher salt efficiency obtained indicates that the concentration of nitrate by chromatographic action on the column should be taken into account when estimating salt removal efficiency. The present model used in estimating this parameter assumes an even distribution of nitrate throughout the bed. The estimates of BV(N), however, are made with the chromatographic effect taken into account. It is also likely that lower leakages are obtained because the columns had not reached equilibrium, i.e. they had not been operated repeatedly at the same salt dosages before the data were obtained. This data should be compared with that obtained under repeated and continuous operation in Section 5.

TABLE 9
DATA FOR RUN 01114-P3

```
  label     run     bed vol   nitrate   sulfate   calc'd      calc'd
   of       data                                  Parameter   value
  data       in
--------- --------- --------- --------- --------- ---------  ---------
 Run No =01114-P3  000.0      24.6     000.0
         =========    0.0      24.6               meq NO3
 Resin  =A 101D       0.0      24.6               removed
         ======       0.0      24.6               per liter
 Well No=2            0.0      24.6               resin    =     183.61
         ======       0.0      24.6                            ---------
 Liters               0.0      24.6
   of                15.2      21.6               meq Cl
 Resin  =2407        30.4      19.4               used
         ======      45.6      13.4               per liter
 Liters              60.8       8.8               resin    =    1000.00
 of 6%               76.0       4.4                            ---------
 Brine  =2407        91.2       0.0
         ======     106.4      19.4
 NO3 ppm            121.6      14.8               meq Cl
 in     =70.9       136.8      20.4               used per .
         ======     152.0      22.8               meq NO3
 SO4 ppm            167.2      24.6               removed =        5.45
 in     =120        182.4      23.2                            ---------
         ======     197.6      21.6
 Cl ppm             212.8      33.9
 in     =68.2                                     BV(N)    =      212.8
         ======                                                ---------
 HCO3ppm
 in     =119
         ======                                   meq SO4 =        2.50
 No of                                                         ---------
 Brine                                            meq NO3 =        1.14
 Frac-                                                         ---------
 tions  =Partial                                  meq S+N =        3.64
         ======                                                ---------
==========                                        per litr   influent
 RUN                                                            water
 FORMAT                                           NO3
                                                  removed
                                                  ppm      =       53.5
                                                  (average  ---------
                                                     before    bkth)

                                                  NO3
                                                  leakage
                                                  ppm      =       17.4
                                                  (average  ---------
                                                     before    bkth)
```

TABLE 9
DATA FOR RUN 01114-P3

```
  label      run      bed vol   nitrate   sulfate   calc'd     calc'd
   of        data                                   Parameter  value
  data        in
--------- --------- --------- --------- --------- --------- ---------
 Run No =01114-P3  000.0       24.6     000.0     meq N03
         ========    0.0       24.6               removed
 Resin  =A 101D      0.0       24.6               Per liter
         ======      0.0       24.6               resin   =   183.61
 Well No=2           0.0       24.6                          ---------
         ======      0.0       24.6
 Liters              0.0       24.6
   of               15.2       21.6               meq Cl
 Resin  =2407       30.4       19.4               used
         ======     45.6       13.4               Per liter
 Liters             60.8        8.8               resin   =  1000.00
 of 6%              76.0        4.4                          ---------
 Brine  =2407       91.2        0.0
         ======    106.4       19.4               meq Cl
 NO3 PPm           121.6       14.8               used Per .
 in      =79.9     136.8       20.4               meq N03
         ======    152.0       22.8               removed =     5.45
 SO4 PPm           167.2       24.6                          ---------
 in      =120      182.4       23.2
         ======    197.6       21.6
 Cl PPm            212.8       33.9
 in      =88.2                                    BV(N)   =    212.8
         ======                                              ---------
 HCO3PPm
 in      =119
         ======                                   meq S04 =     2.50
 No of                                                       ---------
 Brine                                            meq N03 =     1.14
 Frac-                                                       ---------
 tions   =Partial                                 meq S+N =     3.64
         ======                                              ---------
=========                                         Per litr  influent
 RUN                                                          water
 FORMAT                                           N03
                                                  removed
                                                  PPm     =     53.5
                                                  (average ---------
                                                     before   bkth)

                                                  N03
                                                  leakage
                                                  PPm     =     17.4
                                                  (average ---------
                                                     before   bkth)
```

TABLE 10

DATA FOR RUN 12143-P1

```
  label   run    bed vol  nitrate  sulfate  calc'd     calc'd
   of     data                              parameter  value
  data     in
--------- --------- --------- --------- --------- --------- ---------
Run No =12143-P1 000.0     41.4    000.0    meq NO3
        ========   0.0     41.4             removed
Resin  = A 101D    0.0     41.4             per liter
        ======     0.0     41.4             resin    =    189.52
Well No= 2         0.0     41.4                        ---------
        ======     0.0     41.4
Liters             0.0     41.4             meq Cl
  of              15.2     36.1             used
Resin   =2407     30.4      9.7             per liter
        ======    45.6      0.0             resin    =   1000.00
Liters            60.8      0.0                        ---------
of 6%             76.0      8.8
Brine   =2407     91.2      4.2
        ======   106.4      0.0             meq Cl
NO3 ppm          121.6      0.0             used per
in      = 70.9   136.8      4.0             meq NO3
        ======   145.0      8.8             removed =       5.28
SO4 ppm          152.0      9.7                        ---------
in      = 120    167.2     13.2
        ======   182.4     21.6
Cl ppm           197.6     39.6             BV(N)    =     197.6
in      = 88.2                                         ---------
        ======
HCO3ppm
in      = 119                               meq SO4 =       2.50
        ======                                         ---------
No of                                       meq NO3 =       1.14
Brine                                                  ---------
Frac-                                       meq S+N =       3.64
tions   =Partial                                       ---------
        ======                              per litr   influent
=========                                               water
RUN                                         NO3
FORMAT                                      removed
                                            ppm      =      59.5
                                            (average ----------
                                               before   bkth)

                                            NO3
                                            leakage
                                            ppm      =      11.4
                                            (average ----------
                                               before   bkth)
```

TABLE 11

EFFECTIVENESS OF DECLASSIFICATION

Run No.	Method of Declassification	Result	BV 6% Salt
11013-P1	Resin was not fully loaded on first three runs. Backwash done for 5 min. V-106 and 5 min. V-107.	Not Satisfactory	1.5
11023-P2			1.5
11093-P3			1.5
11153-P1	Same backwash as above. Unsteady leakage.	Not Satisfactory	2.5
11173-P2	No attempt to mix resin. No backwash	Poor	2.0
11223-P3	Backwash only for 10 min. with no attempt to mix resin.	Low initial leakage High second half	1.5
12143-P1	V-106 only for 16 min.	Very Poor	1.0
12213-P2	V-106 only. On three min. off 3 min. Three times	Improved	1.0
01114-P3	V-106 only. On 3 min. off 3 min. Four times.	Better than 12213-P2	1.0

TABLE 12

COMPARISON OF ACTUAL AND CALCULATED PERFORMANCE

Run No.	BV (N) Calc	BV (N) Actual	Leakage Nitrate Meq/l Calc.	Leakage Nitrate Meq/l Actual	Meq N Removed Per liter resin Calc.	Meq N Removed Per liter resin Actual	Salt BV 6%	Salt lb per Cu. Ft.
11013-P1	251	243	29	11	170	241	1.5	5.61
11023-P2	251	250	29	3	170	274	1.5	5.61
11093-P3	251	259	29	7	170	270	1.5	5.61
11153-P1	278	244	16	10	244	242	2.5	9.35
11173-P2	266	250	21	11	215	241	2.0	7.48
11223-P3	251	228	29	8	170	231	1.5	5.61
12143-P1	229	198	42	11	107	190	1.0	3.74
12213-P2	229	199	42	10	107	195	1.0	3.74
01114-P3	229	213	42	17	107	184	1.0	3.74
2" column	311	313	(VIRGIN RESIN)		-	-	-	-

TABLE 13

REGENERANT EFFICIENCY - PLANT DATA

Run No.	Salt BV of 6% NaCl	Brine Use Factor*	
		Calculated	Actual
11013-P1	1.5	8.82	6.22
11023-P2	1.5	8.82	5.47
11093-P3	1.5	8.82	5.56
11153-P1	2.5	10.25	10.33
11173-P2	2.0	9.30	8.30
11223-P3	1.5	8.82	6.50
12143-P1	1.0	9.35	5.26
12213-P2	1.0	9.35	5.13
01114-P3	1.0	9.35	5.45

$$* \text{ Brine Use Factor} = \frac{\text{Meq Chloride Used in Brine}}{\text{Meq nitrate removed from feed water}}$$

SEMI-AUTOMATIC OPERATION

A period of semi-automatic operation followed the above tests while the TI-500 Controller was being installed and programmed. During this period irrigation type controllers were installed in each control box to automate the regeneration cycle. This was done mainly for operator convenience. Manual control was required to initiate the regeneration cycle and to control the brine pump. The main pump was also under manual control. Nitrate levels of the effluent from each vessel and blended water were also done manually during this period while the analytical chemistry instrumentation was being set up and tested. This period was also used for operator training although the operation was more complex than it eventually became and more analytical chemistry was required of the operator for monitoring purposes. Also during this period only one vessel was operated at a time to further simplify the tasks of the operator.

Data was collected for each vessel exhaustion with service period terminated when nitrate leakage reached 30 mg/l. These runs were made to determine the bed capacity per service cycle.

AUTOMATIC OPERATION

Pre-Start Up Checklist

Automatic operation of the plant was accomplished with the TI-500 Controller.

Prior to starting the plant in automatic operation the following steps must be followed:

1. Determine the sequence of vessel operation (1, 2, 3 or 2, 3, 1, or 3, 1, 2) and set the switch on the controller accordingly. The lead vessel (the first to be exhausted) is designated by the first number. The vessel in standby is designated as the last number. If the plant has previously been in operation, the lead vessel is determined as the one showing the highest flow reading on the batch register.

2. If the resin in each vessel is regenerated, the end-of-batch should be set at one-half its value for the lead vessel and at the full value for the other two. It is then readjusted on the lead vessel to the full value after it is regenerated. (If it is necessary to change the end-of-batch setting, set the full value on each vessel and immediately after start-up manually give an end-of-batch signal for the lead vessel.)

3. Turn well pump lever switch to ON and set pump switch to automatic.

4. Turn controller ON. Annunciator will show each vessel in stand-by.

5. Push sequence selector button.

6. Push controller button. Annunciator lights will show status of each vessel. Pumps will start in five minutes. If vessels will now yn mewn Qaogmua% de dYdoj unehmwmon has occurred. Correct alarm condition as indicated on computer print-out and push alarm reset button. Then push controller button again.

7. Turn nitrate analyzer ON.

8. Check recorders for paper and ink in pens.

To turn plant off, shut off power to pumps. Leave controller ON. Annunciator will show current status of vessels. Shut analyzer OFF. To restart plant if annunciator shows two vessels in service, restore power to pumps and turn analyzer ON. If all three vessels are in stand-by, start at Step 1 above.

Operational Sequence

The program controlling automatic operation consists of the following sequence of operations (with vessels Nos. 1 and 2 in service and No. 3 in stand-by as examples):

1. A signal from the end-of-batch meter on vessel No. 1 is received by the controller.

2. Vessel No. 1 is taken out of service and vessel No. 3 is put in service. Vessel No. 2 remains in service and at this time is one-half exhausted.

3. After a one minute delay brine and drain valves are opened on vessel No. 1. Brine pump starts pumping saturated brine. Water supply for diluting brine is turned ON.

4. Water supply for diluting brine continues to flow for five minutes to rinse brine from piping.

5. Slow rinse valves are opened on vessel No. 1. Vessel is

rinsed for 53 minutes. Slow rinse valves are closed.

6. The backwash discharge valve is opened on vessel No. 1.

7. Declassification valves are alternately opened and closed to complete declassification.

8. The backwash discharge valve is closed on vessel No. 1.

9. Vessel No. 1 remains in stand-by until the end-of-batch signal is received from vessel No. 2.

The above sequence is repeated for regenerating vessel No. 2 and No. 3 when the appropriate end-of-batch signals are received by the controller.

Alarm Conditions

The following alarm conditions will cause plant shut-down:

1. Nitrate levels in the blended water exceeding 45 mg/l as nitrate. This alarm level is set by the adjustment on the recorder.

2. Electrical conductivity of the treated water exceeding the set value. This value is set at the recorder and is set at approximately 10% above the normal value.

3. Power failure. This condition was added because there is no way to automatically restart the controller at the same place in the operational sequence after power is again restored. Consequently, the plant can only be restarted by the operator. The operator can determine the last programmed operation by inspection of the plant and by reviewing the print-outs which are produced prior to power failure and after power is restored.

Computer print-outs of the plant conditions and the cause for the alarm are given immediately after the plant is shut-down for the first two reasons. The print-out after power loss is not given until power is restored.

Other Shut-Down Conditions

Other shut-down conditions occur when the pressure to the distribution system exceeds the set value (approximately 65 psi) and when the pressure at the discharge of the booster pump exceeds 100 psi.

Computer Print-Out Reports

The microprocessor gives five types of reports for plant monitoring and for research purposes. The report types are:

1. Daily Report. This report is shown in Figure 26. One is automatically produced each midnight and totals the flows from the previous midnight.

2. Manual Report. A sample is given in Figure 27. This report is obtained at any time by the operator by activating a switch on the control panel. The report contains the same data as the Daily Report except flows are totaled from midnight to the time of the report.

3. Regeneration Report. A sample is given in Figure 28. This report gives detailed flow and conductivity of waste brine. This report assures the operator that a vessel was properly regenerated. This report will also be useful for brine reuse studies.

4. Variables Report. A sample is given in Figure 29. The control and reporting variables are listed which can be entered into the microprocessor.

5. Alarm Report. A sample is given in Figures 30 and 31. The information is the same as the Manual Report except the condition of the alarm is indicated.

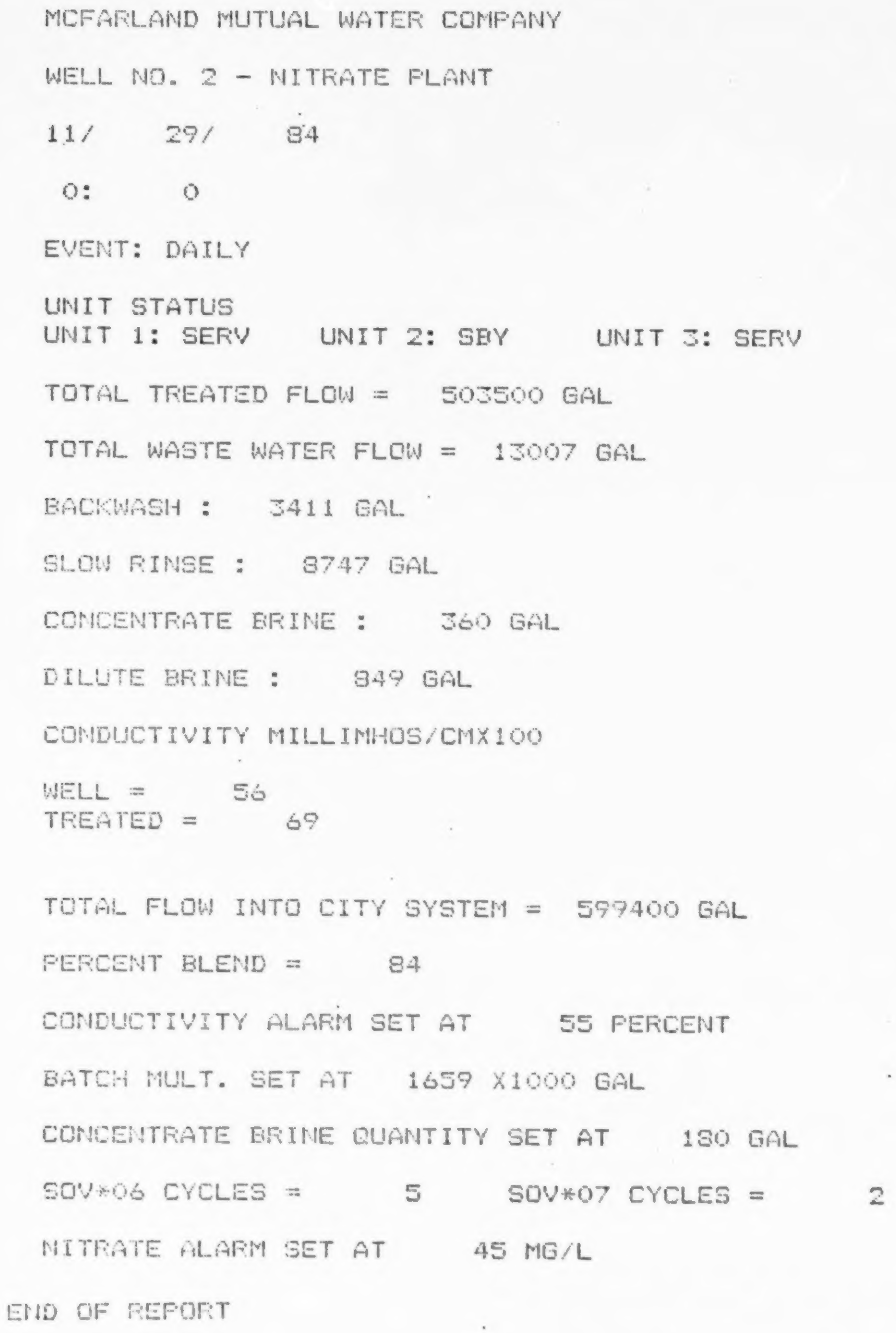
Chart Recordings

Twenty-four hour chart recordings are made of nitrate levels in delivered water and electrical conducicitivities of treated and well water. Examples are shown in Figures 32 and 33.

Weekly chart recordings of instantaneous flow rates of water delivered to the distribution system are also made at the Water Company office. An example is given in Figure 34.

OPERATIONAL PROBLEMS

The problems associated with the operation of the plant from the start-up period were due to pipe breaks, minor plumbing leaks, gasket leaks, and some of electromechanical nature. In general, none were serious to disable the plant for lengthy time periods and most could be repaired by Water Company personnel. The major problems experienced during this early period of operation involved the ion chromatograph system used for monitoring the nitrate levels in the distributed water.

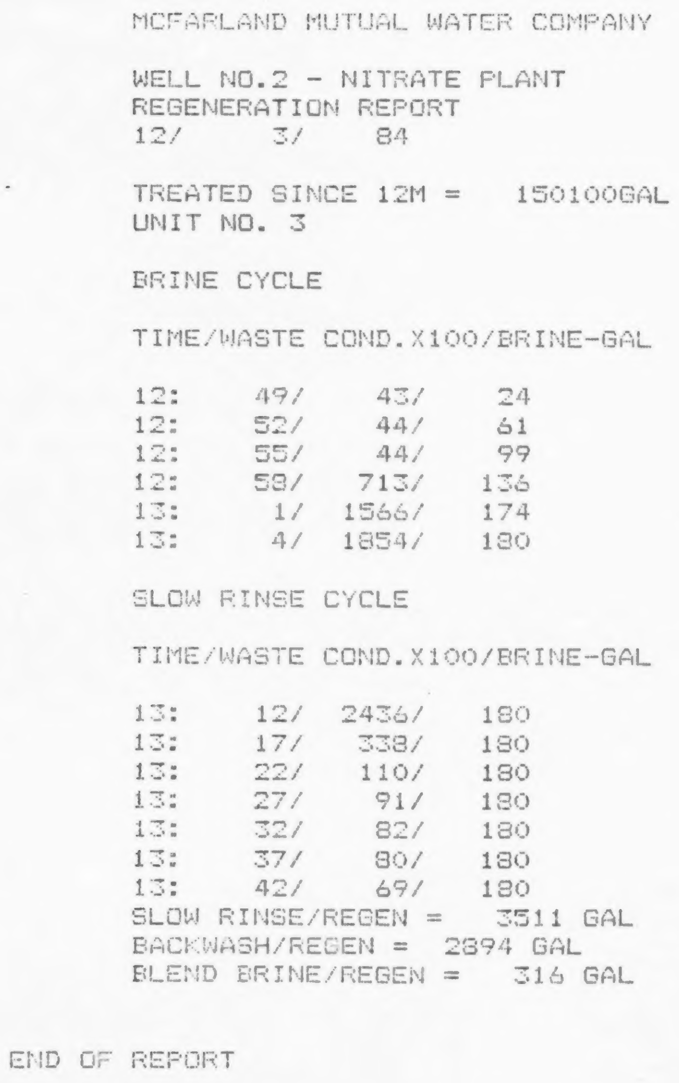


```
MCFARLAND MUTUAL WATER COMPANY

WELL NO. 2 - NITRATE PLANT

11/    29/    84

 0:      0

EVENT: DAILY

UNIT STATUS
UNIT 1: SERV    UNIT 2: SBY     UNIT 3: SERV

TOTAL TREATED FLOW =    503500 GAL

TOTAL WASTE WATER FLOW =  13007 GAL

BACKWASH :   3411 GAL

SLOW RINSE :   8747 GAL

CONCENTRATE BRINE :     360 GAL

DILUTE BRINE :    849 GAL

CONDUCTIVITY MILLIMHOS/CMX100

WELL =      56
TREATED =      69

TOTAL FLOW INTO CITY SYSTEM =  599400 GAL

PERCENT BLEND =      84

CONDUCTIVITY ALARM SET AT      55 PERCENT

BATCH MULT. SET AT   1659 X1000 GAL

CONCENTRATE BRINE QUANTITY SET AT    180 GAL

SOV*06 CYCLES =       5     SOV*07 CYCLES =       2

NITRATE ALARM SET AT      45 MG/L

END OF REPORT
```

FIGURE 26. DAILY REPORT

```
MCFARLAND MUTUAL WATER COMPANY

WELL NO. 2 - NITRATE PLANT

11/    27/    84

15:    42

EVENT: MANUAL

UNIT STATUS
UNIT 1: SERV    UNIT 2: SBY     UNIT 3: SERV

TOTAL TREATED FLOW =   237400 GAL

TOTAL WASTE WATER FLOW =   5296 GAL

BACKWASH :   1297 GAL

SLOW RINSE :   3557 GAL

CONCENTRATE BRINE :     180 GAL

DILUTE BRINE :     442 GAL

CONDUCTIVITY MILLIMHOS/CMX100

WELL =      53
TREATED =      65

TOTAL FLOW INTO CITY SYSTEM =  282600 GAL

PERCENT BLEND =      84

CONDUCTIVITY ALARM SET AT      55 PERCENT

BATCH MULT. SET AT   1659 X1000 GAL

CONCENTRATE BRINE QUANTITY SET AT    180 GAL

SOV*06 CYCLES =      5     SOV*07 CYCLES =       2

NITRATE ALARM SET AT     45 MG/L

END OF REPORT
```

FIGURE 27. MANUAL REPORT



```
MCFARLAND MUTUAL WATER COMPANY

WELL NO.2 - NITRATE PLANT
REGENERATION REPORT
12/      3/     84

TREATED SINCE 12M =    150100GAL
UNIT NO. 3

BRINE CYCLE

TIME/WASTE COND.X100/BRINE-GAL

12:     49/     43/     24
12:     52/     44/     61
12:     55/     44/     99
12:     58/    713/    136
13:      1/   1566/    174
13:      4/   1854/    180

SLOW RINSE CYCLE

TIME/WASTE COND.X100/BRINE-GAL

13:     12/   2436/    180
13:     17/    338/    180
13:     22/    110/    180
13:     27/     91/    180
13:     32/     82/    180
13:     37/     80/    180
13:     42/     69/    180
SLOW RINSE/REGEN =    3511 GAL
BACKWASH/REGEN =  2894 GAL
BLEND BRINE/REGEN =    316 GAL

END OF REPORT
```

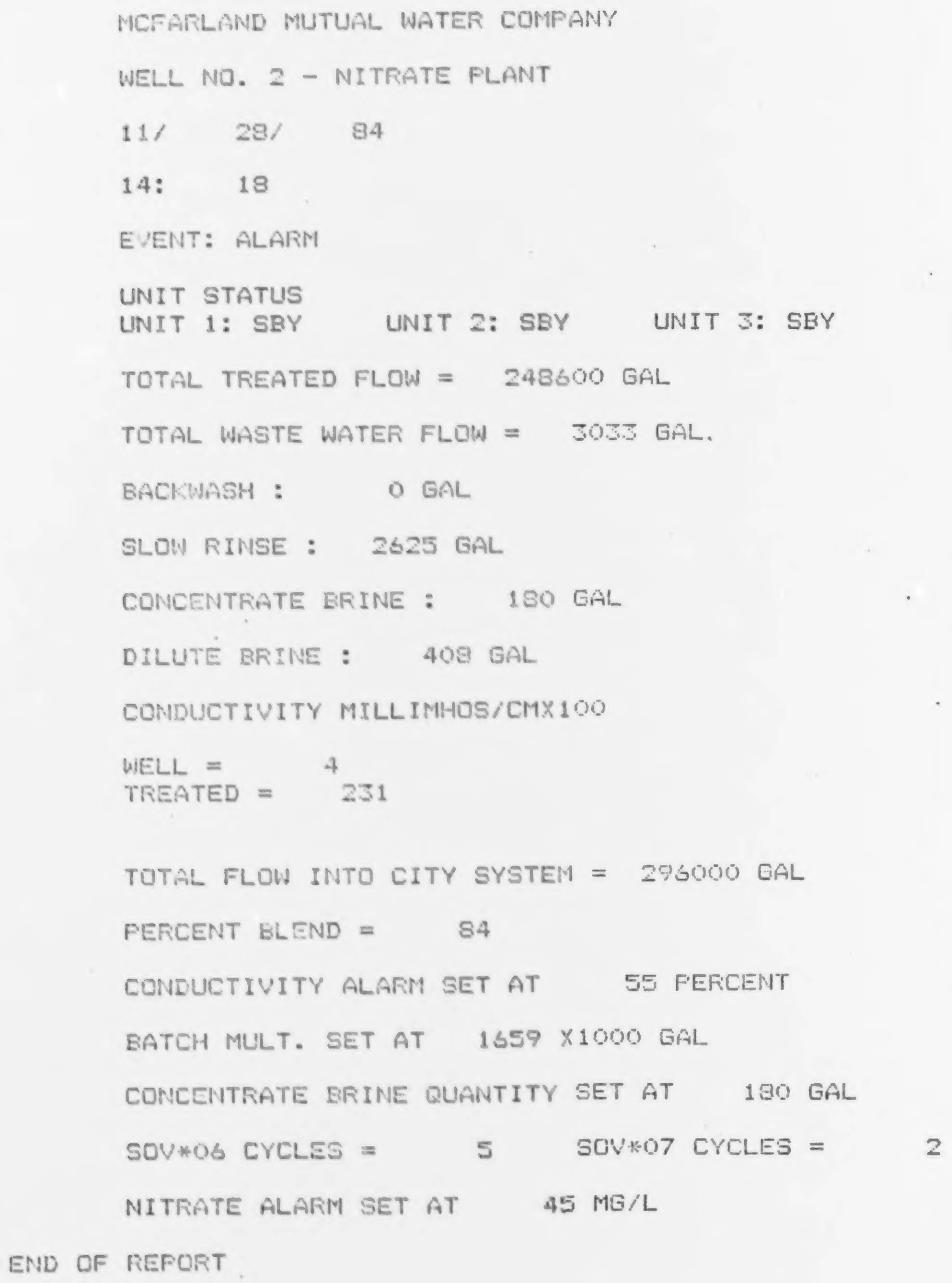
FIGURE 28. REGENERATION REPORT

```
CONDUCTIVITY ALARM SET AT     55 PERCENT

PERCENT BLEND =     84

BATCH MULT. SET AT   1659 X1000 GAL

CONDUCTIVITY ALARM SET AT     55 PERCENT

NITRATE ALARM SET AT     45 PERCENT

CONCENTRATE BRINE QUANTITY SET AT    180 GAL

SOV*06 CYCLES =      5     SOV*07 CYCLES =     2
```

FIGURE 29. OPERATING VARIABLES PRINT OUT

```
        MCFARLAND MUTUAL WATER COMPANY

        WELL NO. 2 - NITRATE PLANT

        11/    28/    84

        14:     4

        EVENT: POWER FAILURE

        UNIT STATUS
        UNIT 1: SBY     UNIT 2: SBY     UNIT 3: SBY

        TOTAL TREATED FLOW =   247800 GAL

        TOTAL WASTE WATER FLOW =   3033 GAL

        BACKWASH :       0 GAL

        SLOW RINSE :   2625 GAL

        CONCENTRATE BRINE :    180 GAL

        DILUTE BRINE :    408 GAL

        CONDUCTIVITY MILLIMHOS/CMX100

        WELL =      24
        TREATED =      0


        TOTAL FLOW INTO CITY SYSTEM =  295000 GAL

        PERCENT BLEND =      84

        CONDUCTIVITY ALARM SET AT     55 PERCENT

        BATCH MULT. SET AT   1659 X1000 GAL

        CONCENTRATE BRINE QUANTITY SET AT    180 GAL

        SOV*06 CYCLES =       5     SOV*07 CYCLES =       2

        NITRATE ALARM SET AT     45 MG/L

    END OF REPORT
```

FIGURE 30. ALARM REPORT : POWER FAILURE



```
MCFARLAND MUTUAL WATER COMPANY

WELL NO. 2 - NITRATE PLANT

11/     28/     84

14:     18

EVENT: ALARM

UNIT STATUS
UNIT 1: SBY      UNIT 2: SBY      UNIT 3: SBY

TOTAL TREATED FLOW =    248600 GAL

TOTAL WASTE WATER FLOW =    3033 GAL.

BACKWASH :        0 GAL

SLOW RINSE :    2625 GAL

CONCENTRATE BRINE :     180 GAL

DILUTE BRINE :     408 GAL

CONDUCTIVITY MILLIMHOS/CMX100

WELL =        4
TREATED =      231

TOTAL FLOW INTO CITY SYSTEM =  296000 GAL

PERCENT BLEND =      84

CONDUCTIVITY ALARM SET AT      55 PERCENT

BATCH MULT. SET AT    1659 X1000 GAL

CONCENTRATE BRINE QUANTITY SET AT     180 GAL

SOV*06 CYCLES =        5      SOV*07 CYCLES =        2

NITRATE ALARM SET AT      45 MG/L

END OF REPORT
```

FIGURE 31. ALARM REPORT HIGH CONDUCTIVITY

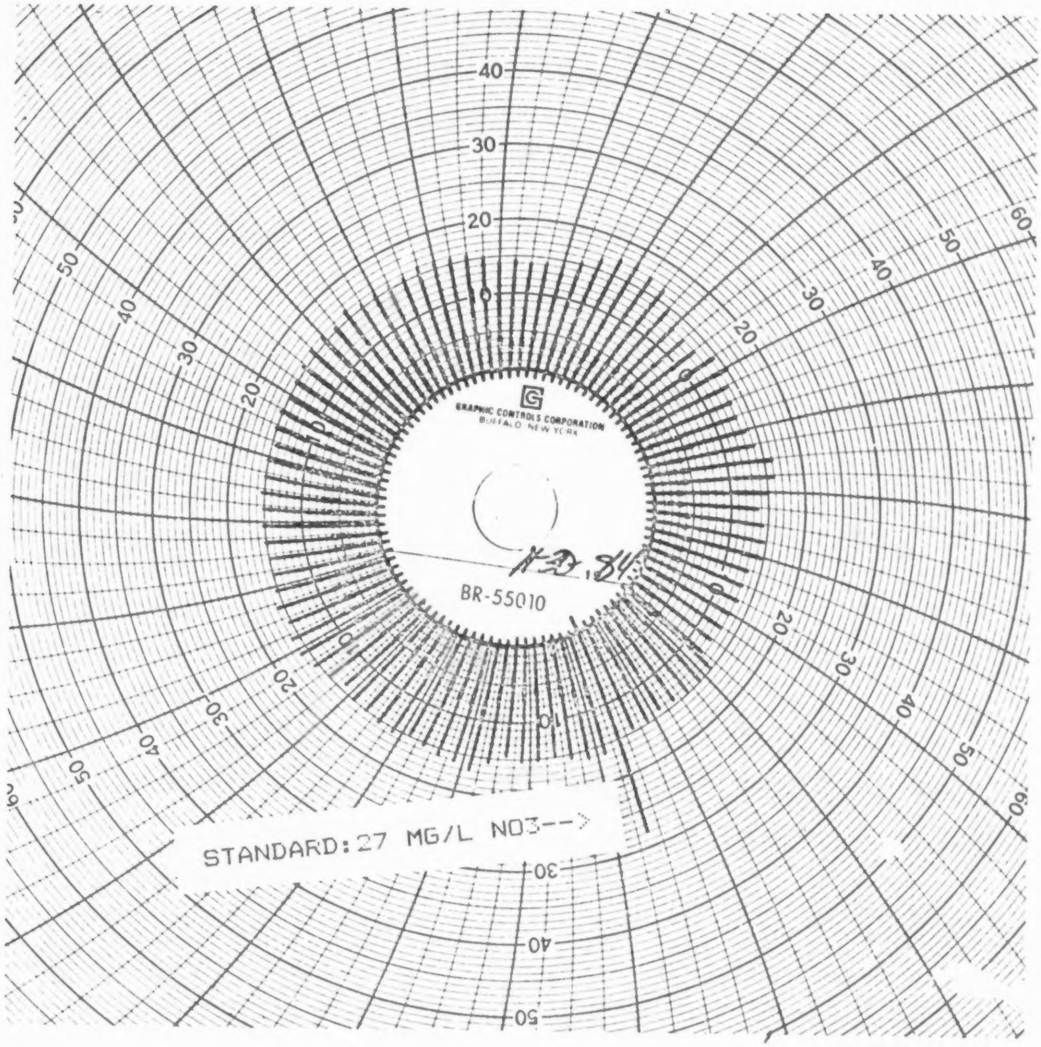


FIGURE 32. NITRATE LEVEL RECORDING

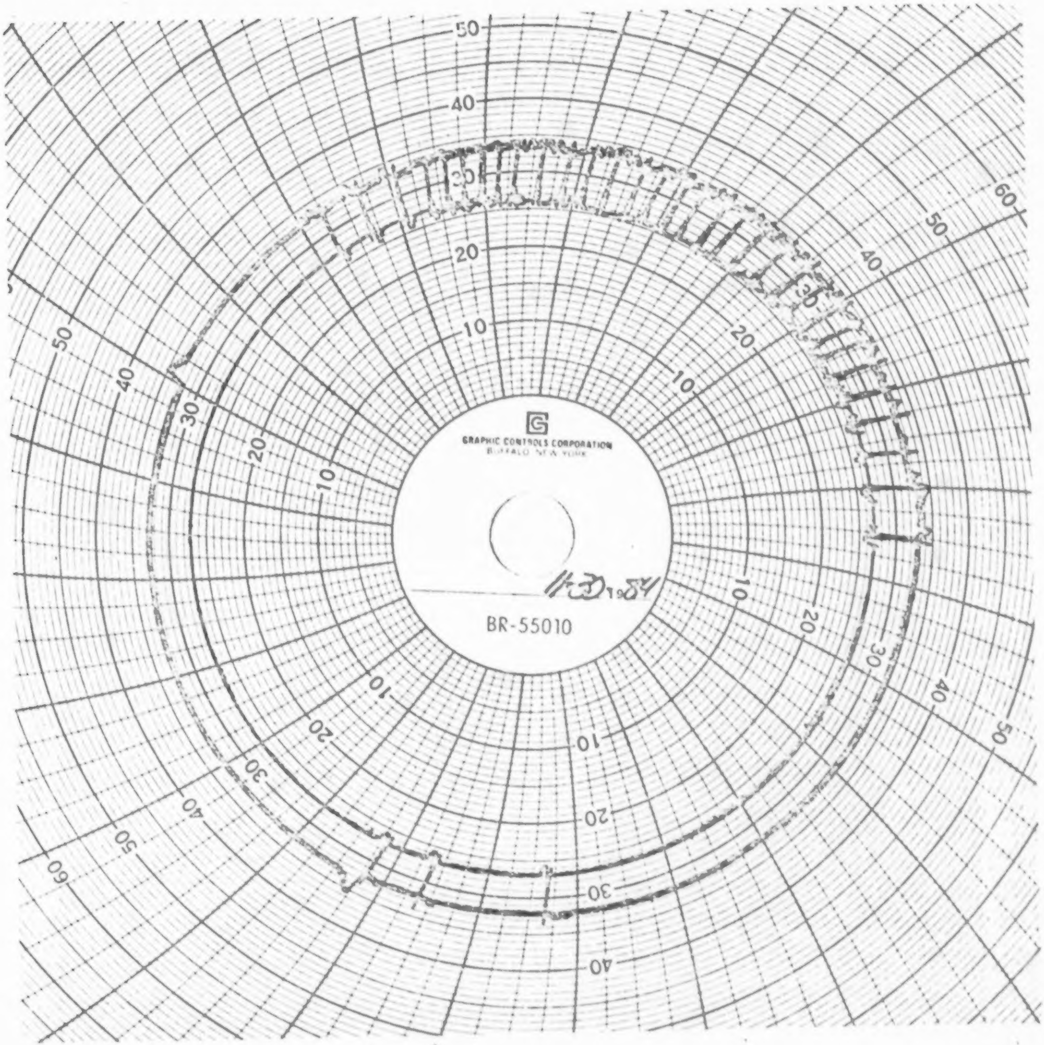
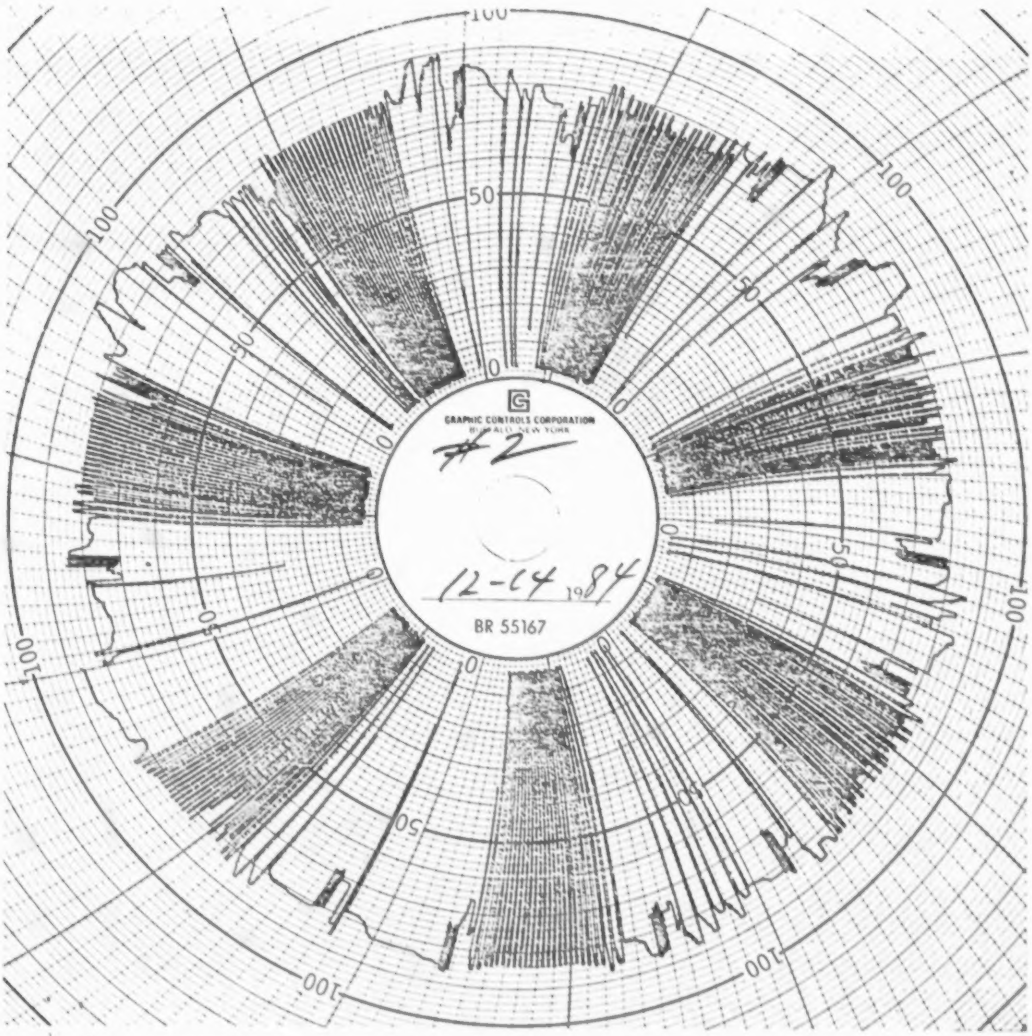


FIGURE 33. ELECTRICAL CONDUCTIVITY OF RAW AND TREATED WATER.



NOTE: 100 ON SCALE EQUALS 1000 GPM

FIGURE 34. CONTINUOUS SEVEN DAY RECORD OF FLOW RATE TO DISTRIBUTION SYSTEM

1. Piping breaks occurred in the main feed water line to the plant causing a severe leak. This break occurred during very hot weather and at the flanged junction between plastic and steel pipes. The area was fully exposed to sunlight and raised the surface temperature of the plastic pipe, forcing it to bend and placing an eneven pressure against the steel flange. Repairs were made using a flexible coupling between the two types of pipe.

   The main product water line was also repaired in the same way after a leak started to occur at a similar junction.

2. The lower manway on Unit 3 developed a leak which could have caused a serious loss of resin if it had not been promptly found and repaired. This leak occurred when the manway gasket imploded into the vessel, loosening the manway and starting a leak of water and resin. This leak was detected after the vessel had been placed in stand-by after regeneration. At this time the pressure in the vessel usually rises from atmospheric to system pressure. It is believed this leak occurred due to the loose manway coupled with the rapid drop of internal pressure as the vessel changes from service to regeneration. At this time the internal pressure can become negative when the vessel is opened to the atmosphere and a partial vacuum is created due to the weight of the water column in the vessel. This would only occur before any brine water inlet valves are opened.

   Replacement and resealing the gasket required removal of the resin from vessel No. 3 and lowering the water level to below the manway. This was accomplished using a suction veturi. A one-inch pipe was placed through the top of the vessel into the resin bed and attached to the venturi fitting to which a one-inch flexible hose was attached. The resin was drawn out of vessel No. 3 through the top and into vessel No. 2. This operation required about 3 hours. After replacing the manway gasket resin was drawn from vessel No. 2 back into vessel No. 3 by the same method. Resin levels were adjusted by visual inspection through the site glasses. The plant was placed back into operation on the next day.

   A regular routine of inspecting the gaskets and tightening the manway bolts when the vessels were under pressure was initiated after this experience.

3. Several small plumbing leaks have occurred throughout the year. It is believed these are due to the newness of the

piping and its expansion and contraction due to temperature changes. No leaks occurred on the shop installed piping on the vessels where piping was protected by a canopy cover. All leaks occurred in the field installed piping which is directly exposed to the sun and where long manifold lines are most effected by expansion and contraction.

4. Batch meter failures were experienced three times during the year. Two failures due to defective counter action and one due to failure of the meter to transmit signals to the counter. The defective counters which are of the plug in type were easily replaced. The defective transmitter was easily repaired by an electrician and it involved a mechanical adjustment of a cam and gear arrangement in the flow meter mechanism. One incident of batch meter failure occurred while vessel No. 1 was in service causing the service period to go 50 percent beyond the set point and the bed was not regenerated on schedule. However, the nitrate level in the blended effluent did not rise above 10 mg NO3-N/L or 44.4 mg NO3/L. This was due to the diluting action with effluent from vessel No. 2 which was also in service at the time. Vessel No. 2 regenerated on schedule then vessel No. 1 regenerated immediately after. This caused the vessels to be out of syncronization.

   The batch meter was repaired and the vessels were placed back into operation.

   Had the plant continued to operate out of syncronization it is possible nitrate levels could have rose about the shut-down limit and the alarm situation would have caused a shut down. However, in this case the disorder in vessel operation was detected by the operators' routine inspection prior to the alarm condition.

5. The most troublesome feature of plant operation was to maintain the continuous operation of the ion chromatograph. Due to this problem nitrate monitoring was supplemented by operator analysis of nitrate using a Hach field test kit. It should be emphasized that the ion chromatograph was installed as an experimental test of this type of analysis for plant monitoring. A dual instrument was available. One portion was dedicated to plant monitoring and the other for research purposes.

   Ion chromatography requires high pressure pumping of sample and elluant through very tiny capillary tubes. Pressures up to 1300 psi are needed to pump through .07 inch diameter tubes and finely packed ion exchange columns. Continuous pumping caused pressure increases with subsequent leaks and loss of resolution and variation in retention times and eventual degradation in ability to perform the analysis. The suppliers of the instrument are continually improving the method with new columns, prefilters, and pretreatment columns to overcome these problems. However, we feel high pressure is itself a major contributor to the eventual degredation of the method. These comments are directed to the method for continuous, on-stream plant monitoring used on a 24-hour per day basis throughout the year. The use of the instrument for research purposes, however, was found to be very satisfactory.

To overcome the problem with ion chromatography a different method for nitrate monitoring was and is being tested. The method employs a special low pressure column operating at 300-350 psi (as compared to 1000 or over for DIONEX columns) and uses the same micro valves and tubing as the IC does. Nitrate is measured by conductivity after the sample is chemically conditioned. This method was easily adapted to the instrument in use and has been very successfully operated for about two months to monitor nitrate levels in the blended product water.

SECTION 5

PLANT PERFORMANCE

DAILY OPERATING RECORDS

Daily records of all flow meter readings, chemical analyses, and pressure readings for the entire plant as well as each individual vessel were maintained. This was required during the manual phase of operation to determine adjustment and restart parameters and conditions as well as to monitor and evaluate plant performance. The daily manual recording was continued until automatic recording of all flow and chemical parameters was accomplished. An example of the record forms for these daily reports is given in Figures 35 through 40.

After automatic operation and reporting were initiated reports were obtained from the microprocessor as described in the previous section.

MONTHLY REPORTS

From the daily reports described above, monthly reports were compiled in conformance with the requirements of the operating permit issued by the California State Division of Health. Tables 14 through 19 summarize the daily records for six months of automatic operation. Table 20 summarizes all monthly data.

CHEMICAL COMPOSITION OF WELL AND PRODUCT WATER

During the period of operation covered by this report changes in chemical composition of the well water occurred. Plant operation was not changed in any way to accommodate these fluctuations in major anion concentrations since satisfactory nitrate levels were being obtained in the delivered water. it was also desirable to maintain constant plant parameters to evaluate effects of the changing water quality.

Table 21 lists the chemical composition of monthly samples analyzed by a certified laboratory. Total anion, TDS and electrical conductivity are also listed. The salt dosages and BV(N) values are given as calculated as described in the following section. It is noted that the raw water quality gradually improved. This is thought to be due to seasonal factors but may also be due in part to the high usage of the

McFARLAND MUTUAL WATER CO.
NITRATE REMOVAL PLANT WELL #2 Month ....Year......
OPERATION AND MAINTENANCE REPORT 1 of 3

	Thousand Gallons of Water			Gallons Con Brine	Pounds Salt Used	Weight % Brine Used
Date	To System	Treated By I X	By-Passed			
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
TOTALS						

REMARKS:

FIGURE 35. DAILY OPERATING DATA FORMAT NO. I

McFARLAND MUTUAL WATER CO.
NITRATE REMOVAL PLANT WELL #2 Month ....Year......
OPERATION AND MAINTENANCE REPORT 2 of 3

	Gallons of Waste Water				Total Gallons Waste Water	
Date	Dilute Brine	Slow Rinse	Backwash	Fast Rinse		
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
TOTALS						

REMARKS

FIGURE 36. DAILY OPERATING DATA FORMAT NO. 2

McFARLAND MUTUAL WATER CO.
NITRATE REMOVAL PLANT WELL #2 Month ....Year......
OPERATION AND MAINTENANCE REPORT 3 of 3

	Nitrate Milligrams Per L.			Hours		
Date	Well	Treated By I X	Blend To System	Plant OPerate Maintain		
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
TOTALS						

REMARKS

FIGURE 37. DAILY OPERATING DATA FORMAT NO. 3

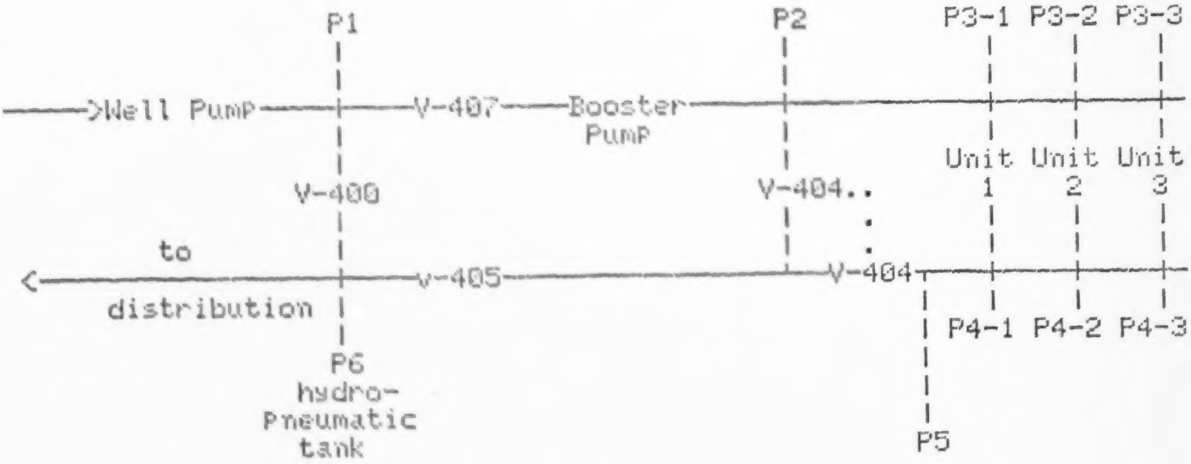
```
                              DALY   FLOWS
DAILY OPERATING LOG
Mc FARLAND MUTUAL WATER CO.
                                          Well temp......C
Date                                      Brine tmp......C
    ----- ---- --- -------                Air  temp......C
      mo   day  yr  time

FT-100   next day .......00               FT-301 next day .........
FT-100   this day .......00               FT-301 this day .........
Gallons to                                Gals dil brine  .........
distribution     .......00                BV brine        .........
                                          Wt % dil brine  .........
#1 meter next day .......00               Eq BV 6% brine  .........
#1 meter this day .......00
#1 treated+fast r .......00               FT-201 next day .........
                                          FT-201 this day .........
#2 meter  next day.......00               Gals slow rinse .........
#2 meter this day .......00
#2 treated+fast r .......00               FT-401 next day .........
                                          FT-401 this day .........
#3 meter next day .......00               Gals backwash   .........
#3 meter this day .......00
#3 treated+fast r .......00               Units fst rinsed.........
                                          Gals per rinse  .........
FT-321   next day .........
FT-321   this day .........               Elec m next d............
Gallons con brine .........               Elec m this d............
Weight % brine    .........               Kwhrs used   ............
==========================
Labor                                     =========================
           hours+ minutes                 Gals treated    .......00
Operation  ....... ........               Gals distributed.......00
Maintenance....... ........               Gals wasted     .........
Describe tasks below:                     Pounds salt     .........
                                          =========================
```

FIGURE 38. DAILY RECORD OF METER READING FORMAT

DAILY OPERATING LOG
McFARLAND MUTUAL WATER CO.
WELL # 2

P1 ..... P2 ..... P3-1 ..... P3-2 ..... P3-3 ..... DATE...........

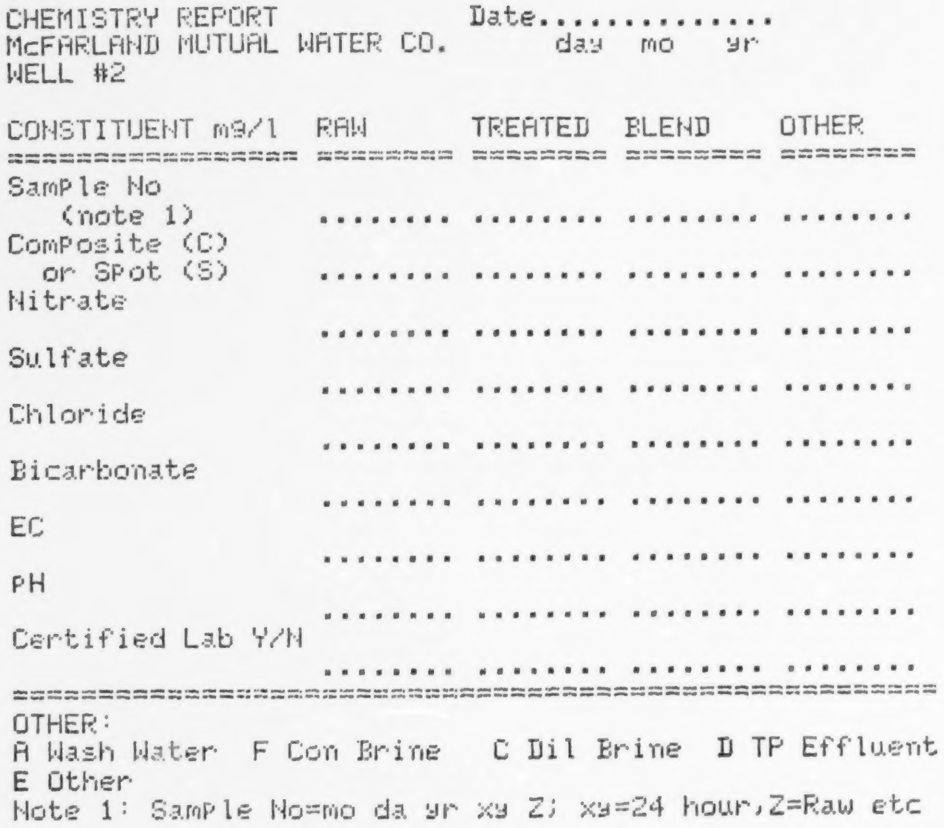
P6 ..... P5 ..... P4-1 ..... P4-2 ..... P4-3 ..... TIME...........


P1
P2
P3-1
P3-2
P3-3
Well Pump
V-407
Booster Pump
Unit 1
Unit 2
Unit 3
V-400
V-404
to distribution
V-405
V-404
P4-1
P4-2
P4-3
P6 hydro-Pneumatic tank
P5

Flow rate to distributiion ...... gpm

Flow rate thru unit#1 ...... gpm, unit#2 ...... gpm, unit#3 ...... gpm

FIGURE 39. DAILY PRESSURE READINGS FORMAT



```
CHEMISTRY REPORT               Date..............
McFARLAND MUTUAL WATER CO.          day  mo   yr
WELL #2

CONSTITUENT mg/l  RAW      TREATED  BLEND    OTHER
================= ======== ======== ======== ========
Sample No
   (note 1)       ........ ........ ........ ........
Composite (C)
  or Spot (S)     ........ ........ ........ ........
Nitrate
                  ........ ........ ........ ........
Sulfate
                  ........ ........ ........ ........
Chloride
                  ........ ........ ........ ........
Bicarbonate
                  ........ ........ ........ ........
EC
                  ........ ........ ........ ........
pH
                  ........ ........ ........ ........
Certified Lab Y/N
                  ........ ........ ........ ........
=====================================================
OTHER:
A Wash Water  F Con Brine   C Dil Brine  D TP Effluent
E Other
Note 1: Sample No=mo da yr xy Z; xy=24 hour,Z=Raw etc
```

FIGURE 40. CHEMISTRY REPORT FORMAT

TABLE 14

PLANT RECORDS JUNE 1984

Date	Gallons of Water			Brine	Average of Daily Nitrate mg/l	Gallons of Waste Water			Total Gallons Wastewater
	To System	Treated By I X	By-Passed			Dilute Brine	Slow Rinse	Backwash	
1	177000	170000	7000	223	21.1	1620	2010	2310	5940
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	173000	160820	12180	197	28.2	1640	3840	2320	7800
5	282000	199800	82200	410	28.2	3480	7890	4950	16320
6	272000	171000	-	366	22.8	3560	8020	5020	16600
7	393000	393000	-	414	19.3	3200	3830	2440	9470
8	209000	209000	-	384	22.9	3370	11470	7470	22310
9	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-
11	323000	323000	-	175	18.1	3110	7320	4400	14830
12	295000	248400	46600	205	20.0	1650	3770	2310	7730
13	321000	165500	55500	345	16.9	3330	7020	4670	15020
14	278000	224300	53700	176	17.9	1940	3670	2270	7880
15	149000	125500	23500	188	21.6	2070	3720	2240	8030
16	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-
18	68000	54800	13200	-	30.1	-	-	-	-
19	349000	283200	65800	378	22.0	3490	7640	4872	16002
20	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-
25	76000	60500	15500	-	22.4	-	-	-	-
26	272000	221500	50500	206	20.4	1760	3510	2260	7530
27	161000	130500	30500	192	20.0	1800	3620	2360	7780
28	-	-	-	-	-	-	-	-	-
29	213000	173900	39100	185	15.9	1650	3660	2530	7840
30	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-
TOTALS	5307000	3515700	1791300	4044	Avg = 21.6	37670	80990	52422	171082

TABLE 15

PLANT RECORDS JULY 1984

Date	Gallons of Water			Brine	Average of Daily Nitrate mg/l	Gallons of Waste Water			Total Gallons Wastewater
	To System	Treated By I X	By-Passed			Dilute Brine	Slow Rinse	Backwash	
1	-	-	-	-	-	-	-	-	-
2	295000	196700	98300	374	25.6	3220	7230	4660	15110
3	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-
6	142000	56500	85500	-	27.3	-	-	-	-
7	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-
10	137000	117000	20000	216	21.6	1610	3770	2520	7900
11	243000	52000	191000	213	18.7	1230	3690	2420	7340
12	224000	89900	313900	178	21.5	1880	3900	2560	8340
13	165000	138400	26600	182	19.8	1500	3960	2550	8010
14	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-
16	269000	227300	41700	341	19.9	3020	7650	4960	15630
17	249000	202800	46200	220	14.3	1510	3700	2600	7810
18	170000	99600	70400	212	19.4	1670	3580	2390	7640
19	392500	392500	-	154	18.4	1590	3890	2600	8080
20	344000	289100	54900	278	18.3	3710	7510	5110	16330
21	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-
24	372000	322200	49800	294	28.5	3620	8370	5120	17110
25	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-
30	287000	238100	50900	199	30.8	1710	3930	2580	8220
31	305000	252500	52500	430	27.5	3000	7460	4710	15170
TOTALS	3595500	2672600	921900	3291	Avg = 22.3	29270	68640	44780	142690

TABLE 16

PLANT RECORDS AUGUST 1984

Date	Gallons of Water			Brine	Average of Daily Nitrate mg/l	Gallons of Waste Water			Total Gallons Wastewater
	To System	Treated By I X	By-Passed			Dilute Brine	Slow Rinse	Backwash	
1	295000	249400	45600	245	17.3	1600	3920	2560	8080
2	345000	300500	44600	401	24.7	60	7570	4940	12570
3	278000	256100	21900	351	22.9	430	8180	5420	14030
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-
6	292000	245400	45600	161	21.9	400	3780	2550	6730
7	251000	219400	31600	175	28.6	370	3650	2800	6820
8	247000	217500	29500	397	29.6	840	6850	5210	12900
9	222000	188300	33700	193	31.2	380	3350	2630	6360
10	265000	221300	43700	194	27.1	390	3470	2680	6540
11	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-
13	220000	189900	30100	196	25.6	390	3520	2520	6430
14	291000	247900	43100	390	24.9	860	6830	5090	12780
15	183000	169400	13600	194	17.8	450	3720	2820	6990
16	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-
21	114000	111600	2400	375	25.1	1540	7500	8420	15920
22	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-
TOTALS	3002000	2616700	385300	3272	Avg = 24.7	7710	62340	47640	117690

TABLE 17

PLANT RECORDS SEPTEMBER 1984

Date	Gallons of Water			Brine	Average of Daily Nitrate mg/l	Gallons of Waste Water			Total Gallons Wastewater
	To System	Treated By I X	By-Passed			Dilute Brine	Slow Rinse	Backwash	
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	41000	32700	8300	216	20.7	1020	3180	2630	6830
6	248000	237400	10600	216	16.6	1090	3810	2730	7630
7	195000	121300	73700	214	21.1	1040	3620	2720	7380
8	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-
10	220200	220200	-	403	25.1	2120	7120	5360	14600
11	276000	254600	21400	180	24.4	1010	3270	2690	6970
12	226000	215100	10900	415	24.9	2120	6950	5280	14350
13	238000	213600	24400	182	25.4	1050	3550	2430	7030
14	261000	235800	25200	167	20.0	1010	3550	2800	7360
15	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-
17	224000	218700	5300	401	26.1	2040	6940	4920	13950
18	231000	210400	20600	177	26.9	970	3760	2470	7200
19	238000	196700	41300	186	26.2	1010	3400	2720	7130
20	317000	222100	94900	195	24.0	990	3250	2630	6870
21	239000	196800	69200	178	22.8	960	3660	2650	7270
22	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-
24	267000	184600	82400	209	21.4	1050	3550	2560	7160
25	282000	198200	83800	215	21.3	1020	3430	2480	6930
26	248000	176500	71500	400	27.0	1830	7400	5140	14370
27	336000	167900	168100	-	24.7	-	-	-	-
28	157500	157500	-	353	23.1	1970	6900	5140	14010
29	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-
TOTALS	4244700	3433100	811600	4307	Avg = 23.4	22300	77340	57350	156990

TABLE 18

PLANT RECORDS OCTOBER 1984

Date	Gallons of Water			Brine	Average of Daily Nitrate mg/l	Gallons of Waste Water			Total Gallons Wastewater
	To System	Treated By I X	By-Passed			Dilute Brine	Slow Rinse	Backwash	
1	193400	193400	-	185	20.8	1070	3560	2450	7080
2	309000	192200	116800	184	21.6	970	3400	2600	6970
3	289000	176100	112900	-	20.6	-	-	-	-
4	272000	170800	101200	343	33.2	1990	6850	5020	13860
5	257000	162400	94600	194	22.0	990	3460	2700	7150
6	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-
8	255000	159300	95700	194	23.4	990	3340	2590	6920
9	202000	130300	72700	393	22.9	1890	6920	5190	14000
10	179000	112000	67000	-	45.6	-	-	-	-
11	44000	27600	16400	-	19.4	70	40	-	110
12	234000	153000	81000	374	23.4	1900	499	5250	7649
13	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-
15	255000	165200	89800	-	25.6	-	-	-	-
16	232000	152100	79700	199	23.3	1420	10191	1030	12641
17	216000	140500	75500	206	23.6	910	3890	1010	5810
18	150000	98300	51700	455	25.9	530	3590	2590	6710
19	221000	142000	79000	180	23.7	970	3520	2670	7160
20	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-
22	235000	147600	874	180	20.7	880	3590	2720	7190
23	156000	99200	568	-	18.7	-	-	-	-
24	283000	180000	1030	125	20.2	1020	3370	2430	6820
25	272000	173800	982	180	21.3	230	3660	2710	6600
26	462000	272500	1895	359	21.5	790	7480	5840	13310
27	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-
29	21000	6300	14700	1	22.7	-	-	130	130
30	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-
TOTALS	4738400	3054600	1583800	3752	Avg = 23.8	16620	67360	46130	130110

TABLE 19

PLANT RECORDS NOVEMBER 1984

Date	Gallons of Water								
	To System	Treated By I X	By-Passed	Brine	Average of Daily Nitrate mg/l	Gallons of Waste Water Dilute Brine	Slow Rinse	Backwash	Total Gallons Wastewater
1	-	-	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-
14	188000	156100	31900	325	22.6	180	4110	1600	5890
15	262000	221500	40500	195	24.2	30	4300	1980	6310
16	250000	223000	27000	180	21.7	280	4090	1890	6260
17	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-
19	154000	130000	24000	207	25.7	200	1630	4820	6650
20	-	-	-	-	-	-	-	-	-
21	45000	37200	7800	413	20.8	980	7200	2950	11130
22	-	-	-	-	-	-	-	-	-
23	251000	210700	40300	179	21.6	310	3600	1950	5860
24	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-
26	192000	167100	24900	360	25.3	680	7210	3910	11800
27	378000	319900	58100	359	26.3	880	7210	3270	11360
28	732000	604900	127100	539	23.5	1300	12460	5600	19360
29	658000	539200	118800	718	23.1	1390	14430	1270	17090
30	661000	552900	108100	539	20.0	960	10820	2200	13980
31	-	-	-	-	-	-	-	-	-
TOTALS	3771000	3162500	608500	4012	23.2	7190	77060	31440	115690

TABLE 20

SUMMARY OF MONTHLY DATA

Month	Salt Dose*		% Treated* in Blend	Nitrate mg/l* in Blend	1000 Gal Delivered
	Lbs/Cu Ft	Lbs/1000 Gal of Blend			
6-84	5.94	2.01	66.2	21.2	5,307
7-84	6.36	2.42	74.0	22.3	3,595
8-84	6.46	2.89	87.2	24.7	3,002
9-84	6.48	2.69	80.9	23.4	4,245
10-84	6.35	2.10	64.5	23.8	4,738
11-84	6.55	2.82	83.8	23.2	3,771
Averages	6.36	2.49	76.1	23.2	4,110

* Monthly averages

TABLE 21

CHANGES IN WELL WATER COMPOSITION OVER 11 MONTHS

Month	Nitrate	Sulfate	Bicarbonate	Chloride	ec	TDS	Total Anion	BV(N)[1]	Salt*
1-84	71	115	104	88	840	537	7.72	254	5.33
4-84	65	95	113	84	800	590	7.25	285	4.90
5-84	60	100	100	77	750	490	6.86	286	4.59
6-84	56	95	86	75	*(NA)	443	6.40	298	4.25
7-84	58	85	70	74	610	386	5.94	308	4.13
8-84	50	80	69	68	600	397	5.52	331	3.63
9-84	49	76	75	58	590	390	5.24	340	3.47
10-84	51	60	78	60	590	370	5.04	366	3.37
11-84	62	80	82	62	*(NA)	350	5.76	307	4.19

* NA = Not Available

** Lbs NaCl/Cu Ft to give 30 ppm nitrate leakage at 100% bed utilization.

well made possible by the nitrate plant.

The plant was set in January 1984 to treat 260 bed volumes of water per each service cycle and a brine dosage of approximately 5.61 lbs/cu ft (1.50 BV of 6%) to accommodate the water analysis for that month although that brine dosage was not always obtained as seen in the records given below. The change in water quality demanded less regenerant and longer bed life for optimum performance as shown in Figure 41. Consequently, it was assumed that process inefficiency would result from holding bed life at 260 BV and salt dosages around the 5.61 value and that the loss of efficiency could be estimated and compared to actual data. The data on TDS and conductivity were obtained to see if these easily measured parameters could be used to estimate bed life and salt dosage for maximum efficiency.

Table 22 lists the monthly data on water compositions of raw, treated and blended water from certified laboratory analysis. The January treated water nitrate (26 mg/l) agrees with the leakage estimate of Figure 41 (28 mg/l). The leakages are seen to drop as water quality improved. Nitrate leakage values are discussed in the following section.

EVALUATION OF PRIMARY PLANT PERFORMANCE

For the purpose of this analysis plant performance data is considered to be primary and secondary in nature. Primary performance relates to chemical factors involved in the process such as nitrate leakage, regenerant used, brine efficiencies and effluent histories. These factors together with the resin used determine the primary adjustments which must be made to operate the plant successfully and efficiently. These parameters are also predictable based on various models of resin interaction with feed and product waters.

Secondary performance factors relate to non-critical plant adjustments such as the amount of water used for diluting brine, blending raw with treated water, and backwashing. These factors, although important for proper plant operation, are not critical for achieving best chemical efficiency but are more related to hydraulic efficiency. These parameters are more or less left to the operator to determine and may vary due to physical design of the plant.

TABLE 22

MONTHLY ANION ANALYSES CERTIFIED LABORATORY
MG/L

Month	Nitrate+			Sulfate			Bicarbonate			Chloride		
	raw	trt	blnd	raw	trt	blnd	raw	trt	blnd	raw	trt	blnd
1-84	71	26	40	115	0	34	104	100	102	88	203	169
4-84	66	21	37	95	0	38	113	21	38	84	208	161
5-84	60	20	28	100	0	16	100	38	80	77	226	177
6-84	56	13	26	95	0	27	87	75	50	75	177	158
7-84	58	14	24	85	0	21	70	57	67	74	174	148
8-84	50	10	14	80	0	0	69	61	55	68	155	154
9-84	49	3	20	76	0	17	75	43	49	58	148	128
10-84	51	13	31	60	0	36	80	21	50	60	166	112
11-84	62	17	28	80	0	28	82	47	54	62	159	121

* 0 = less than 5

+ Concentration of nitrate listed as mg NO3/L.
  To convert to mg NO3-N/L divide by 4.43

CRITERIA OF PRIMARY PERFORMANCE

Primary performance data is evaluated by comparing the actual performance data with that which can be estimated from ion exchange theory. The major parameters of interest here are nitrate leakages and the consumption of regenerant salt per amount nitrate removed from raw water. During this period of operation only one brine dosage (although brine dosages varied due to lack of precision control) and bed life were used while blending percentages were frequently altered. The latter parameter is not considered an adjustment to the ion exchange system "per se" but rather an adjustment to the distribution system only because changes in blend percentages do not effect brine efficiency (BUF).

Three criteria can be used to evaluate plant performance. These are:

1. Salt Dosage Requirements
2. Brine Use Factors
3. Nitrate Leakages
4. Effluent Histories

These quantities can be estimated from theoretical considerations and compared to actual performance.

ESTIMATES OF SALT DOSAGE, BRINE USE FACTOR, AND NITRATE LEAKAGE

The amount of salt required for regenerating a nitrate spent bed can be estimated by the method described in Reference 1 provided a Type I or II strong base anion resin is used. Various factors must be known or closely estimated about the feed water and product water compositions and resin properties. Actually, before attempting operation of the plant such a calculation should be made to adjust initial salt loading and useful bed volumes to breakthrough, BV(N).

From the chemical analysis of Well 2 water obtained in January 1984 and using 1300 meg/l for the resin anion capacity and the value of 4 for the nitrate to chloride selectivity constant, K(N,C) the data in Figure 41 was obtained. The first four lines represent the known feed water composition. The fifth and seventh line are the resin properties of the strong base anion exchange resin. The sixth line is the calculated amount of BV(N) for the completely regenerated resin. The eighth line is the nitrate leakage which is desired in the initial portion of treated water. The remainder of the data are calculated from the above inputs.

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                 WATER AND COLUMN CHEMISTRY
                  FOR 100% BED UTILIZATION

NITRATE MG/L        = 71
SULFATE MG/L        = 115
CHLORIDE MG/L       = 88
BICARBONATE MG/L    = 104
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 322
NITRATE-TO-CHLORIDE EQ CONST                         = 4
NO3 MG/L IN TREATED WATER                            = 28
MOLE FRACTION NO3 IN TREATED WATER                   = .0584628376
MOLE FRACTION NO3 ON RESIN AT RUN START              = .198956641
BV(N)'OF REGENERATED RESIN                           = 258.055753
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 2.25340203
MOLE FRACT.NO3 ON RESIN END OFRUN                    = .336629065
POUNDS NACL/CU FT TO REMOVE NO3                      = 3.44948615
POUNDS NACL/CU FT RESIN NEEDED                       = 5.70288818
BV OF 6% NACL NEEDED                                 = 1.52483641
BRINE USE FACTOR                                     = 9.51986949
POUNDS NACL/1000 GAL TREATED WATER                   = 2.95447087
PER CENT TREATED IN BLEND                            = 95.3488372
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 2.81705362
```

**FIGURE 4. WATER AND COLUMN CHEMISTRY
JANUARY 1984 (100%)**

Using these estimate the plant was adjusted in January, 1984, to use 1.5 BV of 6% salt as regenerant and 165,900 gallons for each service cycle or 260 BV(N) to give an approximate nitrate leakage of 28 mg/l.

In November 1984 the water quality at Well 2 had gradually changed to that shown in Table 21. A second set of calculations based on the November water quality are given in Figure 42. The calculations show that if salt dosage were kept at the same level as above a longer BV(N) can be obtained as well as more efficient Brine Use Factor, BUF (meq regenerant per meq of nitrate removed). Although the water quality of Well 2 improved during this period no adjustments were made to increase the volume of water treated per service cycle. Consequently, lower BUF factors were not realized. Instead, blending was varied to take advantage of the improved water quality. This could be done on a day to day basis without disturbing the plant operation. However, as seen below, efficiency was sacrificed. From Figure 42 the November water at 23 mg/l initial nitrate leakage 329 bed volumes could be treated instead of the 260 for which the plant was adjusted at the salt load being used (1.5 BV of 6%). Thus only about (260/329)x100 or 79% of the bed was actually in use by ending the service cycle at 260 bed volumes. Instead of obtaining a brine use factor of 7.15 as indicated in Figure 42 this factor would be 7.15 x 329/260 = 9.05.

Consequently, one would expect BUF to be about the same as it was in January and to remain in the 8 to 9 range. The actual BUF values obtained are given in Figure 42 on a month to month basis and are seen to average 10.3 throughout the six month period.

One of the important conclusions which can be drawn from this analysis is that salt usage can be decreased by allowing the length of the service cycle to adjust to either incoming water quality or to nitrate breakthrough. This would require frequent manual adjustment or automation sensitive to chemical analysis. In this case a salt savings of 100x(8.48-7.06)/8.48 or 17% could be realized based on this calculation. This conclusion will be tested in future operation.

The data of Table 23 summarizes the brine usage data obtained over the six month period of operation as calculated from the monthly records of Tables 14 through 19 and Table 22. It is noted that salt dosages were higher than the target value of 1.5 BV of 6% brine. This was due to the inability of the brine system to deliver a reliable consistent brine dosage. The system relied on a timer controlling the run length of a

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              WATER AND COLUMN CHEMISTRY
               FOR 100% BED UTILIZATION

NITRATE MG/L        = 62
SULFATE MG/L        = 80
CHLORIDE MG/L       = 62
BICARBONATE MG/L    = 82
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 420
NITRATE-TO-CHLORIDE EQ CONST                        = 4
NO3 MG/L IN TREATED WATER                           = 23
MOLE FRACTION NO3 IN TREATED WATER                  = .0644331186
MOLE FRACTION NO3 ON RESIN AT RUN START             = .215983084
BV(N)'OF REGENERATED RESIN                          = 329.699885
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 2.00279306
MOLE FRACT.NO3 ON RESIN END OFRUN                   = .375515286
POUNDS NACL/CU FT TO REMOVE NO3                     = 3.54241609
POUNDS NACL/CU FT RESIN NEEDED                      = 5.54520914
BV OF 6% NACL NEEDED                                = 1.48267624
BRINE USE FACTOR                                    = 7.14915339
POUNDS NACL/1000 GAL TREATED WATER                  = 2.24852405
PER CENT TREATED IN BLEND                           = 82.0512821
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.84494281
```

FIGURE 42 WATER AND COLUMN CHEMISTRY
NOVEMBER 1984 (100%)

TABLE 23

MONTHLY BRINE EFFICIENCIES

Month	Brine Use Factors*			Average	Salt Dose	
	1	2	3		Lbs/CuFt	BV 6% Brine
6-84	7.5	8.5	9.0	8.3	5.94	1.59
7-84	8.6	9.1	9.9	9.2	6.36	1.70
8-84	14.7	10.2	10.5	11.8	6.46	1.73
9-84	13.1	11.8	9.2	11.4	6.48	1.73
10-84	9.8	13.3	10.9	11.3	6.35	1.70
11-84	9.2	10.5	9.5	9.7	6.55	1.75
Average	10.5	10.6	9.8	10.3	6.36	1.70

* 1 = From monthly averages of Hach kit nitrate analysis

2 = From nitrate analysis by certified lab on blended product

3 = From nitrate analysis by certified lab on treated water only

$$\text{Brine Use Factor} = \frac{\text{Equivalents of Chloride in Fresh Regenerant}}{\text{Equivalents of Nitrate Removed from Influent Water}}$$

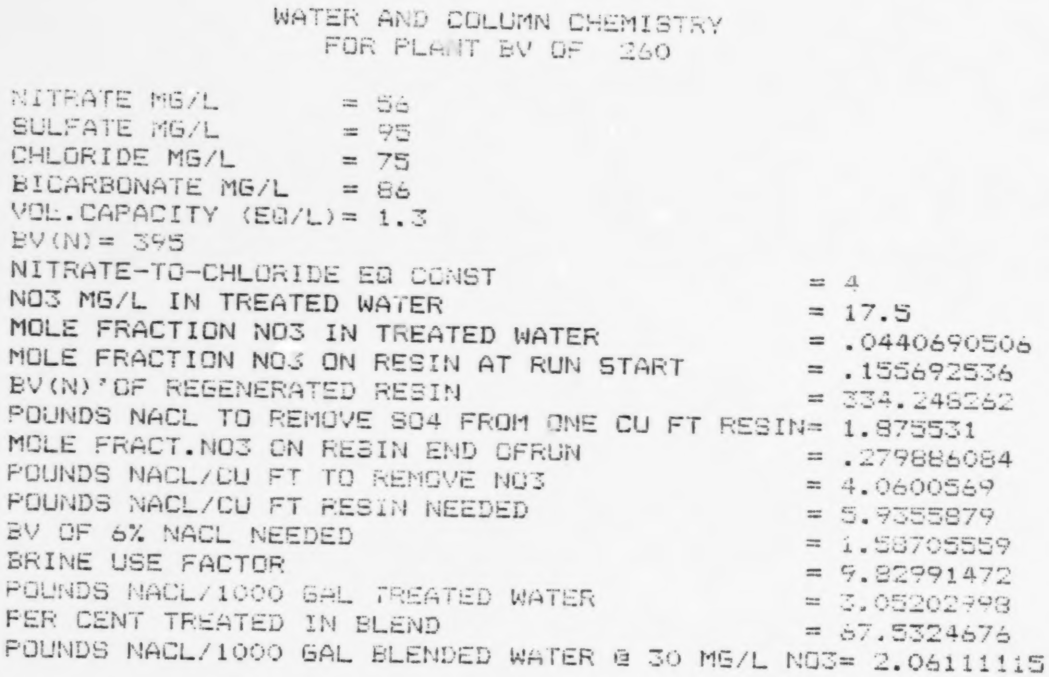
centrifugal brine pump. Brine rate of delivery varied due to variations of brine and diluting water pressures. Consequently, brine rate was manually adjusted frequently and was also adjusted to slightly higher than the 8 gpm required as a minimum brine flow rate. Changes in brine control were later made by reprogramming to terminate the batch on flow rather than time. The estimated performances at the brine dosages listed in Table 23 are given in Figures 43 through 48.

Table 24 provides a comparison of the actual chemical data obtained over the six month period with that which was estimated for a plant using 260 BV service period. The estimated nitrate leakages and BUF values were estimated based on the actual brine dosages used in the plant.

Nitrate leakages obtained by the plant are in good agreement with the predicted values. The actual leakages can be less than predicted because in the partially regenerated bed nitrate leakage gradually drops as the bed is operated due to the depletion of nitrate at the exit end of the bed. Also, any failure to obtain proper declassification will give an erroneous nitrate analysis. The nitrate leakages in Table 24 are from grab samples for certified lab analyses and are subject to variations of sampling and analytical errors.

The plant BUF values of Table 24 are the average monthly values taken from Table 23 where both daily Hach analyses and monthly certified lab analyses are taken into the averaging process. The data show that the plant is about 3 percent less efficient than is predicted. This is quite remarkable considering the estimates which are made in the method used for making these predictions. (Reference 1) One gross assumption in the model used is that nitrate and sulfate are absorbed homogeneously throughout the bed. In actuality nitrate concentrates at the interface between the operating portion of the bed and the unused portion. Wherever nitrate is concentrated less regenerant is required to remove it due to the shape of the regeneration curve. Consequently, lower BUF values in operation may be expected than those predicted. Another way to look at this is that sulfate absorption in the upper portion of the bed moves the nitrate closer to the bed exit making less work for the regenerant to remove the nitrate.

Because the bed is partially used the distribution of ions in such a bed especially after several cycles is probably closer to the models' assumption of homogeneous distribution than would be found in a fully used bed. One would expect, therefore, that better brine efficiency would be obtained for 100 percent bed use than is predicted by the model.



```
                 WATER AND COLUMN CHEMISTRY
                    FOR PLANT BV OF  260

NITRATE MG/L          = 56
SULFATE MG/L          = 95
CHLORIDE MG/L         = 75
BICARBONATE MG/L      = 86
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 395
NITRATE-TO-CHLORIDE EQ CONST                           = 4
NO3 MG/L IN TREATED WATER                              = 17.5
MOLE FRACTION NO3 IN TREATED WATER                     = .0440690506
MOLE FRACTION NO3 ON RESIN AT RUN START                = .155692536
BV(N)'OF REGENERATED RESIN                             = 334.248262
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 1.875531
MOLE FRACT.NO3 ON RESIN END OFRUN                      = .279886084
POUNDS NACL/CU FT TO REMOVE NO3                        = 4.0600569
POUNDS NACL/CU FT RESIN NEEDED                         = 5.9355879
BV OF 6% NACL NEEDED                                   = 1.58705559
BRINE USE FACTOR                                       = 9.82991472
POUNDS NACL/1000 GAL TREATED WATER                     = 3.05202998
PER CENT TREATED IN BLEND                              = 67.5324676
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 2.06111115
```

FIGURE 43. WATER AND COLUMN CHEMISTRY
JUNE 1984 (260 BV)

```
                 WATER AND COLUMN CHEMISTRY
                    FOR PLANT BV OF  260

NITRATE MG/L        = 58
SULFATE MG/L        = 85
CHLORIDE MG/L       = 74
BICARBONATE MG/L    = 70
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 417
NITRATE-TO-CHLORIDE EQ CONST                        = 4
NO3 MG/L IN TREATED WATER                           = 14.97
MOLE FRACTION NO3 IN TREATED WATER                  = .0406596098
MOLE FRACTION NO3 ON RESIN AT RUN START             = .144956781
BV(N)'OF REGENERATED RESIN                          = 356.964369
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 1.67810669
MOLE FRACT.NO3 ON RESIN END OFRUN                   = .283763232
POUNDS NACL/CU FT TO REMOVE NO3                     = 4.68485061
POUNDS NACL/CU FT RESIN NEEDED                      = 6.3629573
BV OF 6% NACL NEEDED                                = 1.70132548
BRINE USE FACTOR                                    = 9.42832191
POUNDS NACL/1000 GAL TREATED WATER                  = 3.27177977
PER CENT TREATED IN BLEND                           = 65.0708808
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 2.12897592
```

FIGURE 44. WATER AND COLUMN CHEMISTRY
JULY 1984 (260 BV)

```
                 WATER AND COLUMN CHEMISTRY
                    FOR PLANT BV OF  260

NITRATE MG/L        = 50
SULFATE MG/L        = 80
CHLORIDE MG/L       = 68
BICARBONATE MG/L    = 69
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 458
NITRATE-TO-CHLORIDE EQ CONST                      = 4
NO3 MG/L IN TREATED WATER                         = 11.97
MOLE FRACTION NO3 IN TREATED WATER                = .0349769843
MOLE FRACTION NO3 ON RESIN AT RUN START           = .12662143
BV(N)'OF REGENERATED RESIN                        = 400.635087
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 1.57939453
MOLE FRACT.NO3 ON RESIN END OFRUN                 = .249298849
POUNDS NACL/CU FT TO REMOVE NO3                   = 4.88398972
POUNDS NACL/CU FT RESIN NEEDED                    = 6.46338425
BV OF 6% NACL NEEDED                              = 1.72817761
BRINE USE FACTOR                                  = 10.8362843
POUNDS NACL/1000 GAL TREATED WATER                = 3.32341648
PER CENT TREATED IN BLEND                         = 52.5900605
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.74778779
```

**FIGURE 45. WATER AND COLUMN CHEMISTRY
AUGUST 1984 (260 BV)**

```
                 WATER AND COLUMN CHEMISTRY
                    FOR PLANT BV OF  260

NITRATE MG/L           = 49
SULFATE MG/L           = 76
CHLORIDE MG/L          = 58
BICARBONATE MG/L       = 75
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 477
NITRATE-TO-CHLORIDE EQ CONST                        = 4
NO3 MG/L IN TREATED WATER                           = 11.06
MOLE FRACTION NO3 IN TREATED WATER                  = .0340630558
MOLE FRACTION NO3 ON RESIN AT RUN START             = .123619636
BV(N)'OF REGENERATED RESIN                          = 418.708196
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 1.5004248
MOLE FRACT.NO3 ON RESIN END OFRUN                   = .246006732
POUNDS NACL/CU FT TO REMOVE NO3                     = 4.98448798
POUNDS NACL/CU FT RESIN NEEDED                      = 6.48491278
BV OF 6% NACL NEEDED                                = 1.7339339
BRINE USE FACTOR                                    = 10.8981693
POUNDS NACL/1000 GAL TREATED WATER                  = 3.33448826
PER CENT TREATED IN BLEND                           = 50.0790723
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.66988079
```

FIGURE 46. WATER AND COLUMN CHEMISTRY
SEPTEMBER 1984 (260 BV)

```
                WATER AND COLUMN CHEMISTRY
                  FOR PLANT BV OF  260

NITRATE MG/L       = 51
SULFATE MG/L       = 60
CHLORIDE MG/L      = 60
BICARBONATE MG/L   = 78
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 521
NITRATE-TO-CHLORIDE EQ CONST                  = 4
NO3 MG/L IN TREATED WATER                     = 10.7
MOLE FRACTION NO3 IN TREATED WATER            = .0342326144
MOLE FRACTION NO3 ON RESIN AT RUN START       = .124177678
BV(N)'OF REGENERATED RESIN                    = 456.851588
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 1.1945459
MOLE FRACT.NO3 ON RESIN END OFRUN             = .254177678
POUNDS NACL/CU FT TO REMOVE NO3               = 5.1650117
POUNDS NACL/CU FT RESIN NEEDED                = 6.3495576
BV OF 6% NACL NEEDED                          = 1.69774267
BRINE USE FACTOR                              = 10.0458146
POUNDS NACL/1000 GAL TREATED WATER            = 3.26488976
PER CENT TREATED IN BLEND                     = 52.1091811
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.70130732
```

**FIGURE 47. WATER AND COLUMN CHEMISTRY
OCTOBER 1984 (260 BV)**

```
                 WATER AND COLUMN CHEMISTRY
                    FOR PLANT BV OF  260

NITRATE MG/L         = 62
SULFATE MG/L         = 80
CHLORIDE MG/L        = 62
BICARBONATE MG/L     = 82
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 420
NITRATE-TO-CHLORIDE EQ CONST                      = 4
NO3 MG/L IN TREATED WATER                         = 14.6
MOLE FRACTION NO3 IN TREATED WATER                = .0409010231
MOLE FRACTION NO3 ON RESIN AT RUN START           = .145723386
BV(N)'OF REGENERATED RESIN                        = 359.245949
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 1.57939453
MOLE FRACT.NO3 ON RESIN END OFRUN                 = .298626612
POUNDS NACL/CU FT TO REMOVE NO3                   = 4.969853
POUNDS NACL/CU FT RESIN NEEDED                    = 6.54924753
BV OF 6% NACL NEEDED                              = 1.7511357
BRINE USE FACTOR                                  = 8.80967328
POUNDS NACL/1000 GAL TREATED WATER                = 3.36756866
PER CENT TREATED IN BLEND                         = 67.5105485
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 2.27346407
```

FIGURE 48. WATER AND COLUMN CHEMISTRY
NOVEMBER 1984 (260 BV)

The net effects of regenerating a bed which is not 100% used during the service cycle are:

1. The working portion of the bed will have more nitrate removed by fresh brine than is predicted from the above estimates. This, however, may not be a significant amount because of the small amount of resin in the nitrate form.

2. Some of the nitrate removed from the working portion of the bed will be retained in the buffering portion of the bed. This is favored by the high chloride content of the resin in this part of the bed.

EFFECT OF UNDERUSING A BED ON BRINE EFFICIENCY

The method is available to allow comparisons of brine efficiencies for fully used and partially used beds. Water and column chemistry parameters are presented in Figures 49 through 54 for 100 percent utilized beds. The same monthly influent water compositions are used as were used in Figures 43 through 48 using only 260 bed volumes for service. A comparison of estimates for the two different cases is thought to give a valid estimate of brine savings which can be realized if plant adjustments are continually made to keep the bed fully utilized, although, as pointed out above slightly better efficiency is obtained than predicted with the partial bed and even better efficiency may be obtained than predicted with full bed use.

Table 25 summarizes the BUF values for the two different cases. It is seen that the average estimate for brine savings is 17.6 percent if a full bed is used. The 100 percent used bed performances show that a slighly higher nitrate leakage would be obtained together with less blending percentages and less salt requirement per 1000 gallons of blended water.

These estimates will be tested in future operations of the McFarland plant. The major concern in using the full bed is that close and continuous adjustment of the plant is required to conform to water composition changes and the danger of nitrate "dumping" if an over-run should occur. This, in turn, would require close or almost continuous nitrate monitoring.

Effluent Histories

Breakthrough curves can be easily obtained from the McFarland Plant using the sampling ports provided which penetrate into the interior of the bed. Water samples were withdrawn from Port No. 2 which is physically about 40% below the upper surface of the bed (assuming 36-inch bed depth). Hydraulically, the probe was

```
                    WATER AND COLUMN CHEMISTRY
                         FOR 100% SED USE

NITRATE MG/L         = 56
SULFATE MG/L         = 95
CHLORIDE MG/L        = 75
BICARBONATE MG/L     = 87
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 395
NITRATE-TO-CHLORIDE EQ CONST                           = 4
NO3 MG/L IN TREATED WATER                              = 21.76
MOLE FRACTION NO3 IN TREATED WATER                     = .0546568217
MOLE FRACTION NO3 ON RESIN AT RUN START                = .187828895
BV(N)'OF REGENERATED RESIN                             = 321.368869
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 2.3182203
MOLE FRACT.NO3 ON RESIN END OFRUN                      = .324350357
POUNDS NACL/CU FT TO REMOVE NO3                        = 3.62617415
POUNDS NACL/CU FT RESIN NEEDED                         = 5.94439445
BV OF 6% NACL NEEDED                                   = 1.58941028
BRINE USE FACTOR                                       = 8.95550636
POUNDS NACL/1000 GAL TREATED WATER                     = 2.47287531
PER CENT TREATED IN BLEND                              = 75.9345795
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.87776746
```

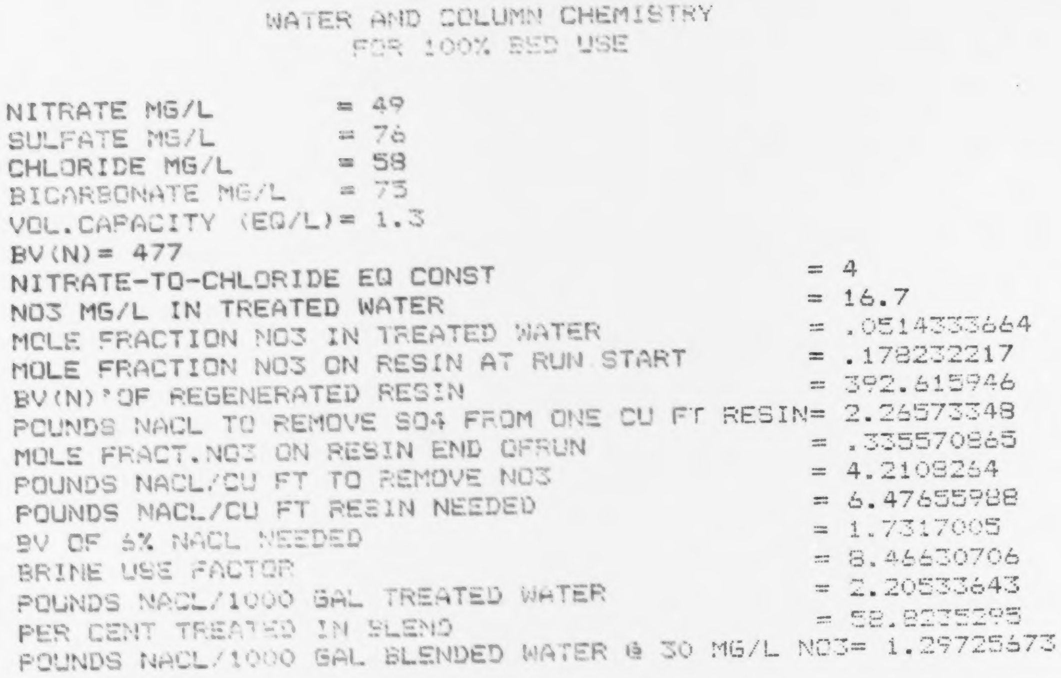
FIGURE 49. WATER AND COLUMN CHEMISTRY
JUNE 1984 (100%)

```
                WATER AND COLUMN CHEMISTRY
                     FOR 100% BED USE

NITRATE MG/L         = 58
SULFATE MG/L         = 85
CHLORIDE MG/L        = 74
BICARBONATE MG/L     = 70
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 417
NITRATE-TO-CHLORIDE EQ CONST                         = 4
NO3 MG/L IN TREATED WATER                            = 19.68
MOLE FRACTION NO3 IN TREATED WATER                   = .0534523126
MOLE FRACTION NO3 ON RESIN AT RUN START              = .184261621
BV(N)'OF REGENERATED RESIN                           = 340.555341
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 2.19803152
MOLE FRACT.NO3 ON RESIN END OFRUN                    = .346173292
POUNDS NACL/CU FT TO REMOVE NO3                      = 4.16276952
POUNDS NACL/CU FT RESIN NEEDED                       = 6.36080104
BV OF 6% NACL NEEDED                                 = 1.70074894
BRINE USE FACTOR                                     = 8.08013658
POUNDS NACL/1000 GAL TREATED WATER                   = 2.49702265
PER CENT TREATED IN BLEND                            = 73.0688935
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.82454697
```

FIGURE 50. WATER AND COLUMN CHEMISTRY
JULY 1984 (100%)

```
                WATER AND COLUMN CHEMISTRY
                     FOR 100% BED USE

NITRATE MG/L          = 50
SULFATE MG/L          = 80
CHLORIDE MG/L         = 68
BICARBONATE MG/L      = 69
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 458
NITRATE-TO-CHLORIDE EQ CONST                         = 4
NO3 MG/L IN TREATED WATER                            = 17.4
MOLE FRACTION NO3 IN TREATED WATER                   = .0508437366
MOLE FRACTION NO3 ON RESIN AT RUN START              = .176459383
BV(N)'OF REGENERATED RESIN                           = 377.773485
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 2.29482068
MOLE FRACT.NO3 ON RESIN END OFRUN                    = .329256103
POUNDS NACL/CU FT TO REMOVE NO3                      = 4.16587658
POUNDS NACL/CU FT RESIN NEEDED                       = 6.46069726
BV OF 6% NACL NEEDED                                 = 1.72745916
BRINE USE FACTOR                                     = 8.69661823
POUNDS NACL/1000 GAL TREATED WATER                   = 2.28636698
PER CENT TREATED IN BLEND                            = 61.3496933
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.40268036
```

FIGURE 51. WATER AND COLUMN CHEMISTRY
AUGUST 1984 (100%)



```
                    WATER AND COLUMN CHEMISTRY
                         FOR 100% BED USE

NITRATE MG/L          = 49
SULFATE MG/L          = 76
CHLORIDE MG/L         = 58
BICARBONATE MG/L      = 75
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 477
NITRATE-TO-CHLORIDE EQ CONST                       = 4
NO3 MG/L IN TREATED WATER                          = 16.7
MOLE FRACTION NO3 IN TREATED WATER                 = .0514333664
MOLE FRACTION NO3 ON RESIN AT RUN START            = .178232217
BV(N)'OF REGENERATED RESIN                         = 392.615946
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 2.26573348
MOLE FRACT.NO3 ON RESIN END OFRUN                  = .335570865
POUNDS NACL/CU FT TO REMOVE NO3                    = 4.2109264
POUNDS NACL/CU FT RESIN NEEDED                     = 6.47655988
BV OF 6% NACL NEEDED                               = 1.7317005
BRINE USE FACTOR                                   = 8.46630706
POUNDS NACL/1000 GAL TREATED WATER                 = 2.20533643
PER CENT TREATED IN BLEND                          = 58.8235295
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.29725673
```

FIGURE 52. WATER AND COLUMN CHEMISTRY
SEPTEMBER 1984 (100%)

```
                  WATER AND COLUMN CHEMISTRY
                      FOR 100% BED USE

NITRATE MG/L          = 51
SULFATE MG/L          = 60
CHLORIDE MG/L         = 60
BICARBONATE MG/L      = 80
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 520
NITRATE-TO-CHLORIDE EQ CONST                         = 4
NO3 MG/L IN TREATED WATER                            = 16.98
MOLE FRACTION NO3 IN TREATED WATER                   = .0539732638
MOLE FRACTION NO3 ON RESIN AT RUN START              = .185807193
BV(N)'OF RESENERATED RESIN                           = 424.012189
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 1.93177654
MOLE FRACT.NO3 ON RESIN END OFRUN                    = .36477611
POUNDS NACL/CU FT TO REMOVE NO3                      = 4.42017817
POUNDS NACL/CU FT RESIN NEEDED                       = 6.3519547
BV OF 6% NACL NEEDED                                 = 1.67838361
BRINE USE FACTOR                                     = 7.299865
POUNDS NACL/1000 GAL TREATED WATER                   = 2.00275328
PER CENT TREATED IN BLEND                            = 61.7283951
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.23626746
```

FIGURE 53. WATER AND COLUMN CHEMISTRY
OCTOBER 1984 (100%)

```
                 WATER AND COLUMN CHEMISTRY
                      FOR 100% BED USE

NITRATE MG/L         = 62
SULFATE MG/L         = 80
CHLORIDE MG/L        = 62
BICARBONATE MG/L     = 82
VOL.CAPACITY (EQ/L)= 1.3
BV(N)= 420
NITRATE-TO-CHLORIDE EQ CONST                     = 4
NO3 MG/L IN TREATED WATER                        = 19.25
MOLE FRACTION NO3 IN TREATED WATER               = .0539277188
MOLE FRACTION NO3 ON RESIN AT RUN START          = .185672235
BV(N)'OF REGENERATED RESIN                       = 342.4464
POUNDS NACL TO REMOVE SO4 FROM ONE CU FT RESIN= 2.08022296
MOLE FRACT.NO3 ON RESIN END OFRUN                = .367304786
POUNDS NACL/CU FT TO REMOVE NO3                  = 4.46687326
POUNDS NACL/CU FT RESIN NEEDED                   = 6.54709622
BV OF 6% NACL NEEDED                             = 1.75056049
BRINE USE FACTOR                                 = 7.41378672
POUNDS NACL/1000 GAL TREATED WATER               = 2.55596276
PER CENT TREATED IN BLEND                        = 74.8538012
POUNDS NACL/1000 GAL BLENDED WATER @ 30 MG/L NO3= 1.91323528
```

FIGURE 54. WATER AND COLUMN CHEMISTRY NOVEMBER 1984 (100%)

TABLE 24

SUMMARY COMPARISON OF ACTUAL CHEMICAL DATA WITH PREDICTED

	PLANT DATA*			ESTIMATED FOR 260 BV**		
Month	Nitrate+ Leakage	Salt Lbs/CuFt	BUF	Nitrate Leakage	Salt Lbs/CuFt	BUF
6-84	13	5.94	8.3	17.5	5.94	9.8
7-84	14	6.36	9.2	15.0	6.36	9.4
8-84	10	6.46	11.8	12.0	6.46	10.8
9-84	3	6.48	11.4	11.0	6.48	10.9
10-84	13	6.35	11.3	10.7	6.35	10.0
11-84	17	6.55	9.7	14.6	6.55	8.8
Averages	11.7	6.35	10.3	12.3	6.36	10.0

* From Table 23

** From Figures 43 through 48

+ Concentration of nitrate listed as mg NO3/L. To convert to mg NO3-N/L divide by 4.43

TABLE 25

ESTIMATES OF BUF FOR FULL BED USE AND PARTIAL BED USE

	BUF		Salt Dose #/Ft^3		% Brine Savings Potential for 100% Bed Use
Month	260 BV	100% Use	260 BV	100% Use	
6-84	9.8	8.9	5.94	5.94	9.2
7-84	9.4	8.1	6.36	6.36	13.8
8-84	10.8	8.9	6.46	6.46	17.4
9-84	10.9	8.5	6.48	6.48	22.0
10-84	10.0	7.3	6.35	6.35	27.0
11-84	8.8	7.4	6.55	6.55	15.9
				Average	17.6

found to be at the 52% mark into the bed due to upward displacement of bed by internals and bed geometry. This was established by running breakthrough curves at this port and at the bottom of the bed with fully regenerated resin and comparing the two breakthrough points. This can be done without discharging over 10 mg NO3-N/L or 44.3 mg NO3/L into the system by stopping the flow at about 9 mg NO3-N/L or 40 mg NO3/L.

Computer estimated breakthrough curves can also be generated using the method described in Reference 2. This method is not described in this report volume. A final version of the program and its use will be described in the final report (Vol. 2).

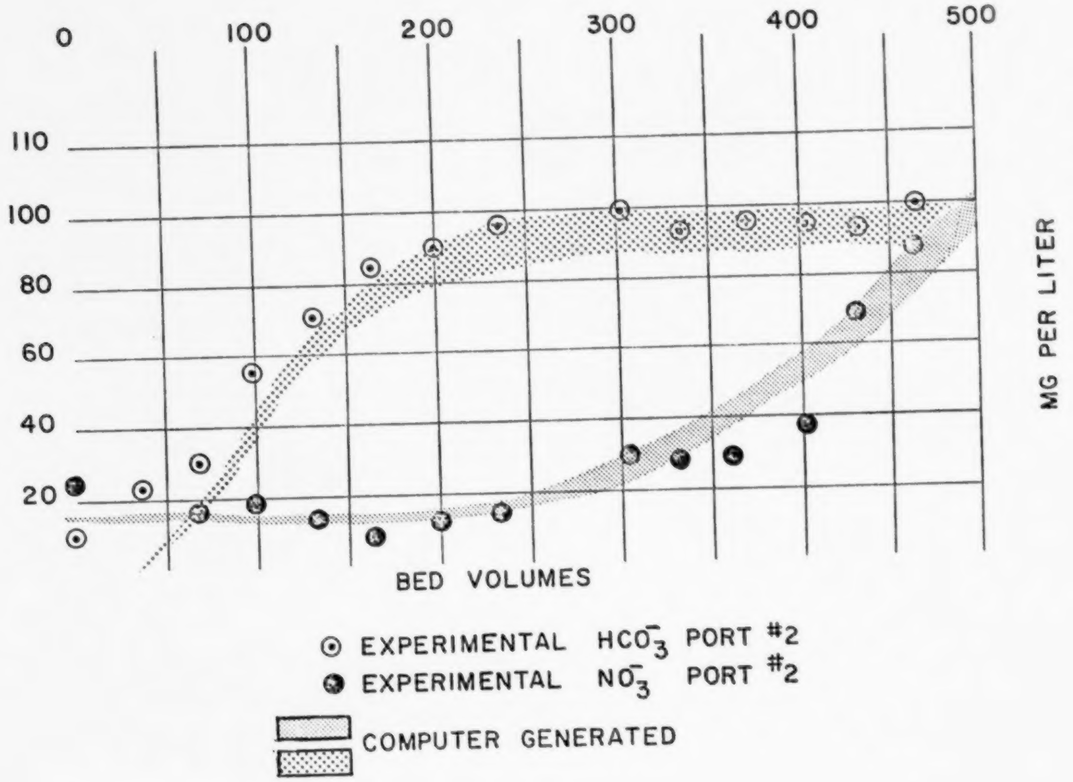
A series of computer produced breakthrough curves is given in Figure 55 for the November, 1984 water composition and the resin parameters shown in Figure 56. The resin composition data of Figure 55 indicates the composition in equilibrium with the effluent composition at the highest bed volume represented on the ordinate. There are several interesting features of a similar set of curves covering a range of bed volumes up to 2000 which are not discussed in this report volume. However, it should be pointed out that if an over-run occurred these curves show nitrate in the product water would exceed the influent value by approximately 50 percent.

The general agreement between actual and computer estimates in Figure 55 is quite good which indicates that the method may be useful for adjusting operation to obtain better efficiency. The experimental data shows a sharper nitrate breakthrough than the computed one. This may well be due to the use of only four theoretical resin plates in the computations. (Computer capacity must be increased to obtain more realistic or sharper breakthroughs.)

It is noted that the bed is under utilized if only 260 bed volumes are treated because it appears from Figure 55 that about 350 to 390 bed volumes could be treated for full utilization (compare also to data of Figure 54). It is not possible to predict from this analysis the quantity of brine which would be required for regeneration. A companion computer program is under development to simulate the regeneration of spent beds having an uneven distribution of ionic compositions.

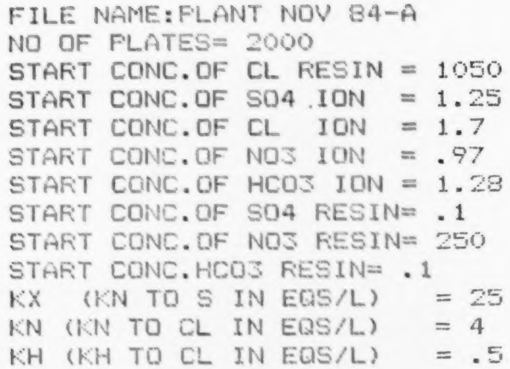
It is also apparent that bicarbonate is present in the effluent at the start of the run. This is not predicted from the computer curves. Apparently not all bicarbonate is removed from the resin upon regeneration.

The conclusion which can be drawn from these data is that the beds display closely predictable effluent histories when using



```
DATA READ BY PROGRAM TITLED NITRE READ-PLOT
FILE NAME FOR ABOVE PLOT IS PLANT NOV 84-A3
RESIN COMPOSITION FOR ABOVE PLOT:
NO OF CALCULATIONS= 155250
RESIN PLATE NO= 3
RESIN CL=   340.591412
RESIN SO4=  8.86113059
RESIN NO3=  843.235267
RESIN HCO3= 107.512545
```

FIGURE 55. COMPARISON OF PLANT DATA WITH COMPUTER GENERATED EFFLUENT HISTORIES.



```
FILE NAME:PLANT NOV 84-A
NO OF PLATES= 2000
START CONC.OF CL RESIN = 1050
START CONC.OF SO4 ION  = 1.25
START CONC.OF CL  ION  = 1.7
START CONC.OF NO3 ION  = .97
START CONC.OF HCO3 ION = 1.28
START CONC.OF SO4 RESIN= .1
START CONC.OF NO3 RESIN= 250
START CONC.HCO3 RESIN= .1
KX  (KN TO S IN EQS/L)   = 25
KN (KN TO CL IN EQS/L)   = 4
KH (KH TO CL IN EQS/L)   = .5
```

FIGURE 56. INPUT DATA FOR COMPUTER CURVE OF FIGURE 55.

the computer program based on numerical solutions to multicomponent equilibria. A further use of the data obtained from computer generated effluent histories is to show the distribution of ions in the spent beds.

SECONDARY PLANT PERFORMANCE FACTORS

Dilute Brine Quantity

The McFarland Nitrate Plant has provisions to mix saturated brine with system water. This is accompliXdna pg ycmping saturated brine from the brine tank, boosting brine pressure to that of the system pressure and allowing brine to mix with water from the system. This mixture then flows to the brine distributor of the vessel in regeneration. Power to the brine pump is controlled by the program. If the brine pump is off fresh water can still flow through the brine delivery system for flushing purposes if so programmed.

The dilution of brine is desireable to prevent a slug of saturated waste brine from entering the municipal waste water system and to prevent osmotic shock to the resin.

The quantities of both saturated and diluted brine are given in Table 26 together with other quantities used for each of the six months.

During August and November dilute brine quantities were reduced to test the brine delivery system. Increased amounts of wash water or backwash water were required to provide sufficient washing to compensate for use of more diluted brine.

The amount of saturated brine is noted to be approximately 0.09% of the total water produced or 0.12% of the amount treated. The corresponding percentages for diluted brine are 0.49% and 0.65%, respectively.

Rinse, Backwash, and Total Wastewater

The amounts used for rinsing, backwash and total wastewater are also given in Table 26.

The plant automatically monitors conductivity of rinse water as shown in Figure 28. Data from one such regeneration is given in Figure 57. It appears that about 30% excess rinse water is used because conductance falls to a constant value at about 2000 gallons. Rinse water was not reduced during this period to allow sufficient rinsing.

TABLE 26

SECONDARY PLANT PERFORMANCE FACTORS

	Thousand Gallons Produced Water		Gallons				
Month	Blend	Treated	Sat. Brine	Dilute Brine	Rinse Water	Backwash	Total Waste
6-84	5307	3516	4044	37670	80990	52422	171082
7-84	3595	2673	3291	29270	68640	44780	142690
8-84	3002	2617	3272	7710	62340	47640	117690
9-84	4245	3433	4307	22300	77340	57350	156990
10-84	4738	3055	3752	16620	67360	46130	130110
11-84	3771	3163	4012	7190	77060	31440	115690
Totals	24598	18457	22678	120760	433730	279762	834252
% of Blend	100	75.0	0.09	0.49	1.76	1.14	3.39
% of Treated	133	100	0.12	0.65	2.35	1.52	4.52

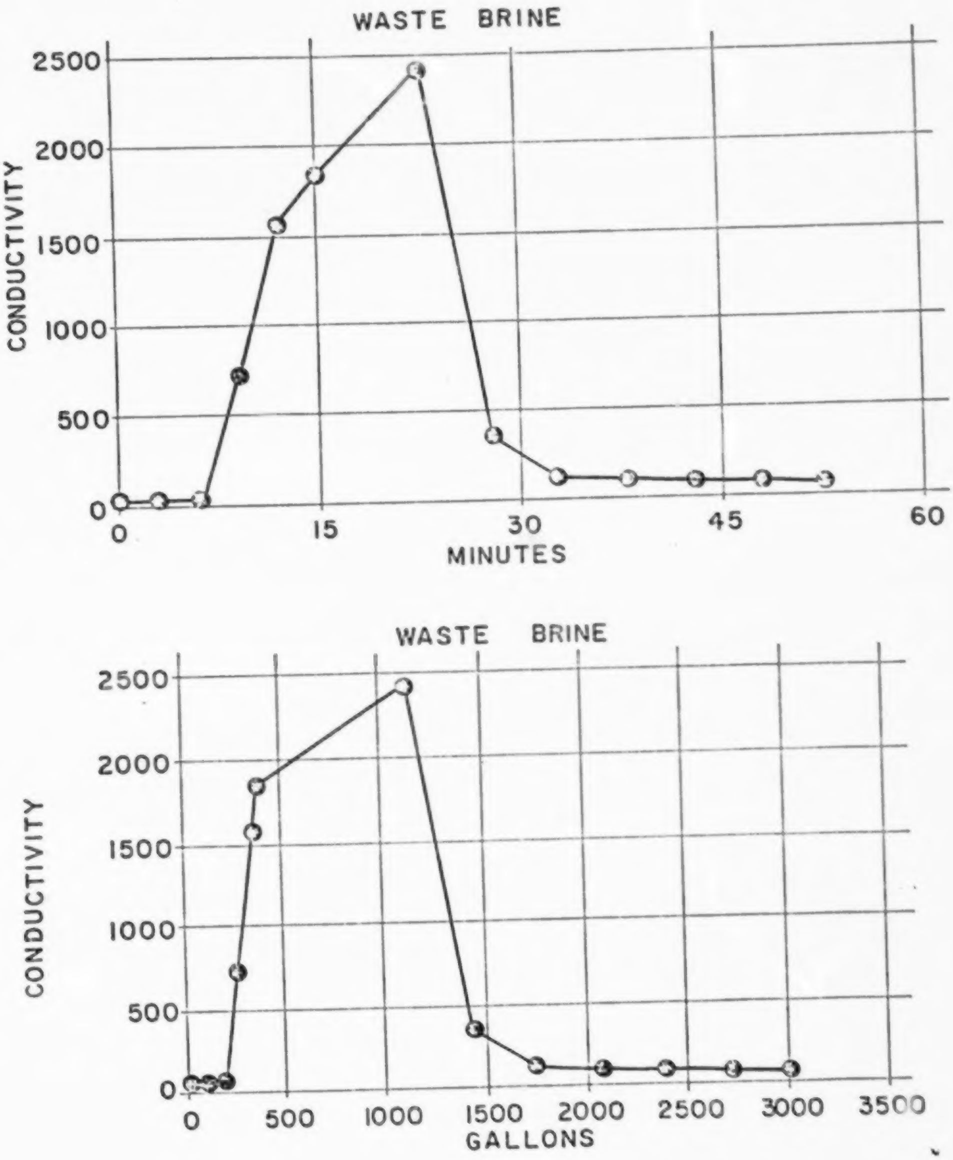


FIGURE 57. WASTE WATER CONDUCTIVITY HISTORY.

The amount of backwash water is determined by the need to declassify the resin after the brining step. If no declassification is required (when nitrate selective resins are used), little if any backwash would be required because of the lack of suspended solids in the source water.

The total waste water over the six month period is 3.39% of the blended water and 4.52% of the treated water. Most of this water is not included in the amount for the distributed water because the rinse and backwash supply are taken upstream of the main meter to the distribution system. The amounts for diluted brine is taken from the downstream of the main meter. Therefore, these amounts must be subtracted from the blend to give true water recovery values. Total blended water is 24598-121=24477 thousand gallons pumped from the well for delivery and an additional 834252 gallons being pumped from the source for waste.

Total water recovery is 96.7% over the six month period.

This high water recovery which is even subject to improvement is one of the main advantages of the ion exchange process over the reverse osmosis process for nitrate removal.

Power Consumption

Daily records of power consumption at the plant have been maintained to obtain electrical power costs for well operation and well plus nitrate plant operation. For the period starting January 11 to May 23, 1984, a total of 14750 KwHr of power were consumed at Well 2 and 6,051,000 gallons of low nitrate water were delivered to the distribution system. This provides an average power requirement of 2.44 KwHr per 1000 gallons of water delivered.

This total power is required to lift water from approximately 250 feet below the surface and pressurize it to between 70 and 75 psi for pumping through the ion exchangers and delivery to a system at between 60 and 65 psi. The pressure drop through the ion exchange system is approximately 10 psi. The amount of power required to pump water through the ion exchange vessels was measured directly from the power meter at the higher pressure limit. Power readings were taken with the well pumping directly into the system and compared to readings taken with the plant in operation. Of the total power consumed at the site 10% was required for the operation of the plant giving 0.244 Kwhr per 1000 gallons the power requirement for plant operation. Power for the brine pump and air compressor are considered negligible.

The cost of this power obtained from the billing of Pacific Gas and Electric Co. is .08183 dollars per Kwhr making power cost for plant operation .019967 dollars per 1000 gallons or 19.97 dollars per million gallons of blended water delivered to the system.

SECTION 6

COST ANALYSES

Costs for construction of the McFarland Plant have been previously published. (Reference 3 and 4). Operation and maintenance costs were estimated in those references without the benefit of long term operation experience. The six months of experience has indicated that only minor changes in the O&M costs need be made.

The capital costs are summarized in Table 27. Costs are given for two different vessel heights. The six foot height accommodates the three foot depth bed and the ten foot height accommodates a five foot depth bed. The cost of the extra side height is the most economical way of increasing bed capacity. By increasing height from six to ten feet bed capacity is proportionately increased. Because the diameter of the vessels does not increase the total plant treatment capacity does not increase. The only operational parameter which is changed is the total gallonage which can be treated per each service cycle. In the long term this will save wear on the valves, brine pump, and air compressor and the nitrate analyzer and consequently lower the maintenance costs.

If present well water quality is maintained over what it has been for the six month period it appears that the three foot bed depth is adequate provided the added maintenance costs do not become excessive.

Table 28 gives a breakdown of equipment and construction items. These costs are taken directly from the construction contracts. The Dionex analyzer and the control enclosure may not be required for a standard plant installation. If the plant is installed in cold climates, additional costs for enclosing the entire plant would be required.

Revised O&M costs are given in Table 29 which reflects actual salt and power costs for the six month period. The costs presented for normal plant maintenance and the miscellaneous costs are left as previously reported as well as the resin replacement costs. These costs may be changed if firm data on resin loss can be obtained. No loss of resin capacity has been detected from the operating data obtained thus far. The one hour per day operator cost is still believed to be adequate since this is mainly a record keeping and inspection effort.

TABLE 27

CAPITAL COSTS, McFARLAND (1983)

Item	Vessel Size 6'D x 6'H	 6'D x 10H*
I.X. Vessels (3 included)	$ 96,511	$111,741
On-site construction	81,151	81,154
Brine tank	18,700	18,700
Other	40,045	40,045
Resin 225 cu. ft. (3 ft. depth)	35,000	
424 cu. ft. (5 ft. depth)		56,610
Sub total	$271,407	$309,250
Engineering & administration 15%	40,711	46,388
Total	$311,118	$355,638

* McFarland's plant

TABLE 28

COST DETAIL FOR EQUIPMENT AND CONSTRUCTION

3 Ion exchange vessels 6'D x 6'H	$ 96,511
+ 4 ft. added H	8,375
+ walkway and ladder	6,855
Sub total ion exchange vessels	$ 111,741
Sewer, catch basin	$ 6,156
Electricial and sample conduits	2,166
Concrete pads	6,400
Booster pump	3,651
Brine pump	1,227
Air compressor	2,073
Steel piping	13,900
Flow, conductivity meters	15,795
PVC piping	4,667
Above gr. electrical	20,603
Set I.X. unites, connect	1,448
Set brine tank	868
Miscellaneous	2,200
Sub total on-site construction	$ 81,154
Brine tank	$ 17,527
Delivery	1,173
Sub total brine tank	$ 18,700
Other	
Control panel	$ 7,614
Dionex	12,455
Control enclosure	9,833
Programmable controller	10,143
Sub total other	$ 40,045

Changes in the above operating costs can be expected to drop due to less salt used to bring the blended water nitrate level to about 30 mg/l as nitrate and if resin replacement is not required as presently estimated. Lower salt demand can also drop due to full bed utilization and brine reuse and/or salt recovery procedures.

Table 30 summarizes the total costs to date including the above revisions. The amortized annual capital cost per 1000 gal is based on 100% use of the 1-mgd capacity. The McFarland plant was only operated at 13.7% of its full capacity during this initial period (See Table 20). In this case the amortized annual capital cost per 1000 gal is 7.30 times that shown in Table 30 or $.832 per 1000 gal. As annual plant production falls from 100% to 0% of full capacity use this cost rises from $0.114 to infinity. O&M costs per 1000 gal are estimated to remain approximately as given in Table 29 regardless of plant useage. The high cost of capital amortization of a partially used plant must be taken into consideration when assessing the cost impact on the consumer. The true water cost which the consumer must pay for operating the plant at less than full capacity can be estimated by comparing consumer costs with and without the plant.

True consumer water costs for this report period reflect the fact that the consumer receives water from the plant as well as from other wells in the system. In this case the capital costs associated with water supply captial costs in McFarland is the capital cost of wells, the distribution system, and related facilities and improvements (not including a nitrate plant), CS, plus the capital costs shown in Table 30, CP. The total consumer cost of amortizing the capital costs (per 1000 gal of water consumed) by producing a fraction of 1-mgd from existing facilities and the remainder from the nitrate plant is:

Total capital cost/1,000 gal = (CDS + CP)/ 1,000 gal.

The additional annual amortized capital cost which the consumer must pay for partial (or full) use of the nitrate plant is the amortized capital cost, $41,773, for the nitrate system as shown in Table 30.

The added cost due to O&M of the nitrate plant during this report period is 0.137 times the O&M cost of Table 29.

The total added consumer cost during this report period due to nitrate treatment of 13.7% of the water supplied to the system is:

$/1000 gal = $0.114 + 0.137 x $0.131

or $0.162

These cost analyses will be presented in more detail when all costs over a two year period of operation are available and will be discussed in Volume II of this report.

The impact of the plant's operation on the cost of water to the community can be assessed by comparing the rates given in Table 31 which were established prior to the construction of the nitrate plant. It is estimated that the average usage of water in McFarland over a one year period is 15,000 gallons per month per connection. This gives the average rate of $.731 per 1000 gallons paid by the consumers. Water costs given in the above tables do not include the normal pumping costs which are estimated to be about $.18 per 1000 gallons.

Total cost of water from Well 2 including electrical power to pump and pressurize water from below the surface plus that required to operate and maintain the plant (full time) would be $.425 per 1000 gallons. This is well within the $.731 average rate charged to the users and allows $.306 per 1000 gallons or 41.8% for administration and management of the water system.

TABLE 29

OPERATION AND MAINTENANCE COSTS

Item	Annual Costs($)	$/1000 gal.
Operation (1 hr/day)	4,745	0.013
Normal O&M, .02X(355,638)	7,133	0.019
*Power, boost pump (.093.kWh)	7,289	0.020
Resin replacement (5 yrs)	11,522	0.032
**Salt ($31.50/ton), 70% cap.	14,314	0.034
Miscellaneous	3,000	0.008
TOTAL O&M	47,983	0.131

TABLE 30

TOTAL COST OF PLANT AND COMPARISON TO PRESENT WATER COST IN McFARLAND

Total Costs (Capital + O&M)

	Annual Costs($)	$/1000/gal.
Capital costs - $355,638 (20 yrs. 10%)	41,773	0.114
Operation & maintenance	47,983	0.131
	89,756	0.245

TABLE 31

PRESENT COSTS OF WATER IN McFARLAND

	$/1000 gals.
First 11,000 gals.	0.980
Over 11,000 gals.	0.468

* 244 kWh per million gallons based on .08183¢ per kWh.
** 2490 lbs. per million gallons.

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1. Guter, G.A. "Removal of Nitrate from Contaminated Water Supplies for Public Use, Final Report," Municipal Environmental Research Laboratory, Office of Research and Development, U.S. EPA, Cincinnati, Ohio. EPA-600/2-82-042, August 1982.

2. Guter, G.A. "Estimation of Resin and Water Composition On Column Performance In Nitrate Ion Exchange", AWWA 1984 Annual Proceedings, Dallas, Texas, June 10-14, 1984, pages 1631 to 1649.

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4. Guter, G.A. "Operation Performance and Cost of the McFarland, CA Nitrate Removal Plant", AWWA Seminar Proceedings, Control of Inorganic Contaminants, Las Vegas, Nevada, June 5, 1983, Pages 29-51.